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Evolution of digital supply chain management in the freight transport industry: A comparative study

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Abstract

This study examines the evolution of digital supply chain management in KwaZulu-Natal's freight transport ecosystem across road, maritime and air. Using a mixed-methods design, we combined expert interviews with a practitioner survey to identify adoption patterns, enablers and constraints. Guided by established lenses including the Technology Acceptance Model, Resource Dependence and Transaction Cost perspectives, we map digital tools in use, perceived benefits and capability gaps. Findings show uneven maturity across modes; leadership commitment, skills development and interoperable data are recurrent enablers, while legacy systems, connectivity and cyber-security concerns persist as barriers. We propose a phased, monitoring-and-evaluation-linked model to support incremental adoption and performance tracking. The study offers practical direction for operators and policymakers on sequencing investments and strengthening governance of digital operations. The focus on a single province and reliance on self-reported perceptions limit wider generalisation, and the sample includes relatively larger firms. Future work should extend comparative analysis to other provinces and include small and micro operators. Overall, the paper contributes an integrated view of digital adoption in a freight hub and a usable model for sector decision-making. The provincial scope (KwaZulu-Natal) and the emphasis on medium-to-large operators limit wider generalisability. Future work will extend the analysis to additional provinces and purposively sample small and micro enterprises to surface size-specific adoption pathways.

Keywords: *digital supply chain management (DSCM), freight transport, maritime logistics, block chain, Artificial Intelligence (AI), supply chain integration*

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1. Introduction

The global goods transport sector is experiencing a substantial transformation due to the incorporation of advanced digital technologies. With the growing complexity, dynamism, and data-centric nature of supply chains, digital supply chain management (DSCM) has become essential for enhancing operational efficiency, visibility, and resilience (Ageron et al., 2020; Queiroz et al., 2022). The digitalisation of freight logistics processes facilitates real-time tracking, predictive analytics, and efficient information exchange across multimodal operations, providing companies with a competitive advantage in unstable and heavily regulated markets (Gunasekaran et al., 2018; Arenkov et al., 2019). In South Africa, freight transportation is fundamental to economic activity, representing a significant share of GDP and trade volume. KwaZulu-Natal (KZN) is notably important because it contains two principal seaports, Durban and Richards Bay, which manage more than 60% of South Africa's maritime traffic (Chasomeris, 2006). Road freight predominates domestic logistics, transporting more than 80% of national freight volumes (Havenga & Simpson, 2018), whereas air freight is essential for the conveyance of time-sensitive, high-value commodities.

Notwithstanding the global trend towards digitalisation, the adoption of DSCM in KZN's goods industry, particularly among small and medium-sized firms (SMEs), is constrained by infrastructural, financial, and organisational obstacles (Wong et al., 2020; Wong & Tang, 2018). Digital transformation in freight logistics provides a means to rectify enduring inefficiencies in routing, cargo handling, port administration, and inventory control (Fruth & Teuteberg, 2017). La and Heiets (2021) argue that technologies such as the Internet of Things (IoT), blockchain, artificial intelligence (AI), and real-time tracking systems are fundamentally transforming operating methods in the goods sector. The magnitude and influence of digital transformations in regional freight ecosystems, such as KZN, are inadequately examined, revealing both research and practical knowledge deficiencies.

While the benefits of DSCM are well acknowledged, freight transport operators in KZN continue to face persistent barriers to effective implementation. High upfront costs, internal resistance to organisational change, concerns around cybersecurity, and difficulties integrating new technologies with outdated legacy systems have collectively constrained widespread adoption, especially among SMEs (Bichou, 2009; Ortwein & Kuchinke, 2021; Miggels & Rulashe, 2022). Moreover, empirical knowledge about the integration of these technologies

across various freight modes and their influence on operational performance in the region is scarce.

The central research problem addressed in this study include:

1. What is the current state of digital supply chain management system adoption in KZN ’s freight transport industry?
2. What challenges impede this adoption?
3. How can freight operators leverage emerging technologies to enhance operational efficiency and competitiveness?

These questions frame the study’s inquiry into the digitalisation of freight logistics within a developing country context, where infrastructure disparities and institutional readiness shape the trajectory of technological uptake. To respond to the problem, the study set out to identify the DSCM systems currently in use across road, maritime, and air freight sectors in KZN. It further examined the operational impacts of these systems on efficiency, inventory management, and service delivery. The research also investigated the challenges encountered by freight operators in implementing these systems, evaluated differences in adoption levels across transport modes, and ultimately proposed a normative model for optimising DSCM implementation within the region’s multimodal freight ecosystem.

This study makes both theoretical and practical contributions. It addresses a significant deficiency in the literature, where scholarly focus on digitalisation has largely centred on manufacturing, retail, and agriculture (Schniederjans et al., 2020), leaving freight transport underexplored, particularly in the context of emerging economies. By focusing on a regional freight system in KZN, this research offers context-specific insights into the dynamics, constraints, and possibilities of digital transformation in logistics. In practical terms, the study provides strategic frameworks and empirically grounded insights that can support decision-making by industry stakeholders, including freight operators, policy-makers, and technology vendors. The normative model proposed offers structured, sector-responsive pathways for incremental adoption, operational improvements, and innovation-led growth. Moreover, the study draws attention to sectoral disparities in digital readiness and presents a foundation for benchmarking and collaborative capacity-building. Importantly, the research aligns with South Africa’s National Freight and Logistics Strategy (Department of Transport, 2022), which articulates the importance of modernising infrastructure and operations to improve economic

competitiveness. As such, the study contributes not only to academic discourse but also to policy implementation and institutional reform across the freight logistics sector.

2. Literature Review

The worldwide freight transport sector is seeing a significant transition due to the incorporation of digital technologies. As goods logistics evolve into a data-centric domain, DSCM becomes an essential tool for improving visibility, responsiveness, and sustainability. In areas such as KZN, South Africa, which hosts essential commercial ports like Durban and Richards Bay, the development of DSCM is especially significant. This literature analysis examines the fundamental concepts, international trends, and regional significance of DSCM in freight logistics, while pinpointing research deficiencies for future investigation. This review is organised thematically: (i) digital transformation in logistics, (ii) conceptualisation and sector-specific challenges in freight operations and DSCM, and (iii) theoretical perspectives on digital adoption relevant to DSCM (TAM, RDT, TCE, DoI).

2.1. Digital Transformation in Logistics Road Freight

In South Africa, road transport predominates freight logistics, comprising more than 80% of freight volumes (Havenga & Simpson, 2018). Digital goods systems facilitate real-time monitoring, load optimisation, and route efficiency. Nevertheless, substantial initial expenses, inadequate infrastructure, and data privacy issues may impede adoption (Riedl et al., 2018; Ortwein & Kuchinke, 2021). Rail and pipeline transportation are economically efficient for bulk commodities, although they exhibit a deficiency in digital advancement. Chechenova and Batalova (2023) identify obstacles that include antiquated systems, reluctance to adapt, and cybersecurity weaknesses. Technologies like as GPS tracking and predictive analytics have opportunities for efficiency improvements when appropriately implemented (Chechenova & Batalova, 2023).

Maritime transport accounts for nearly 95% of South Africa's international trade (Chasomeris, 2006). The region is crucial to national logistics due to its two main ports in KZN. Research indicates that digitisation via technologies such as Electronic Data Interchange (EDI), Internet of Things (IoT), and blockchain promotes cargo monitoring, optimises lead times, and facilitates just-in-time procedures (Fruth & Teuteberg, 2017). Nonetheless, concerns, including system compatibility and cybersecurity, continue to exist.

Air freight: Despite its higher cost, air freight is essential for high-value and time-sensitive shipments. Digitalisation has resulted in improved visibility, automation, and predictive analytics for route optimisation and lead-time reduction (Bierwirth & Schocke, 2017; La & Heiets, 2021). However, integration into comprehensive DSC systems remains inconsistent due to infrastructural and financial obstacles.

KwaZulu-Natal context. KZN is geographically located with two significant ports, Durban and Richards Bay, rendering it an essential hub for national and international trade. The goods transport sector in the region is experiencing a digital revolution, shaped by global trends and local logistical obstacles. Nevertheless, the adoption of digital technologies among SMEs is minimal due to insufficient understanding and resources (Wong et al., 2020). KZN plays a substantial role in South Africa's GDP, with logistics and transport serving as primary economic engines. Its strategic position, commerce infrastructure, and port operations render it a central hub for freight transportation. Notwithstanding worldwide momentum, the implementation of DSCM among freight operators in KZN, particularly SMEs, remains constrained. Wong et al. (2020) observed that numerous enterprises exhibit a deficiency in understanding and training about digital tools, highlighting the necessity for specific legislative interventions and industry assistance.

The current literature on DSCM in transportation predominantly emphasises industries such as manufacturing and agriculture (Schniederjans et al., 2020). Limited research examines its function in freight logistics, especially within regional economies such as KZN. The comprehension of the degree of digital integration, obstacles to adoption, and effects on operational performance in local goods enterprises is limited. This study seeks to address that gap by examining the evolution of DSCM in the goods transport industry of KZN. Digital supply chain management is radically transforming freight logistics, allowing organisations to enhance performance, decrease costs, and swiftly adapt to market fluctuations. Despite significant worldwide progress, regional implementation in KZN encounters infrastructural, budgetary, and strategic obstacles. Addressing these deficiencies necessitates cooperative endeavours among government, industry, and academia. Future research should assess the efficacy of digital adoption in freight operations, specifically across various transport modalities and organisational scales.

Existing research on digital supply chain integration in freight highlights uneven adoption across modes and firm sizes. Interoperability, data visibility and human capability

repeatedly emerge as levers of operational performance, yet modal comparisons within South African provincial ecosystems remain thin, and few studies offer sequenced guidance on how firms can progress from foundational visibility to integrated, analytics-enabled operations. This review, therefore, motivates an empirical assessment of current practices in a high-throughput regional hub and the development of a phased model aligned to monitoring and evaluation.

2.2. Conceptualisation and Sector-Specific Challenges in Freight Operations and Digital Supply Chain Management

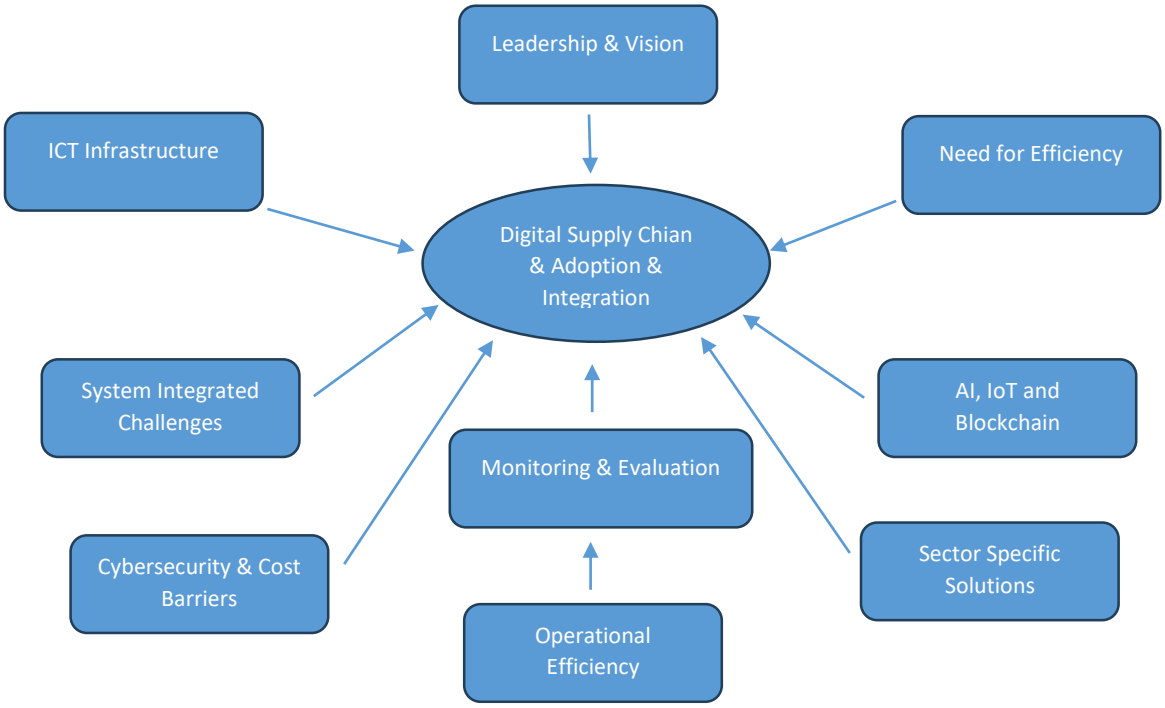
Supply Chain Management (SCM) encompasses the orchestration of sourcing, procurement, logistics, and partner engagement to provide value to customers (CSCMP, 2019). It emphasises the optimisation of upstream and downstream flows, the integration of business operations, and the enhancement of service delivery through strategic alignment (Christopher, 2016; Ivanov et al., 2021). Digitisation pertains to the conversion of analogue data into digital formats, whereas digitalisation involves comprehensive transformations in organisational processes facilitated by digital technology (Legner et al., 2017; Jam et al., 2024; 2025). These concepts are interconnected, with digitalisation serving as the foundation for digitalisation initiatives that transform supply chain strategies and operations.

A Digital Supply Chain (DSC) utilises sophisticated technologies, including IoT, AI, blockchain, and big data analytics, to improve connection, automation, and data-driven decision-making (Arenkov et al., 2019; Ageron et al., 2020). The result is a more agile, resilient, and customer-focused supply chain adept at enduring contemporary challenges. The conceptual framework for this study presents a multidimensional perspective on the adoption and integration of DSCM systems in the freight transport sector of KZN, South Africa. It maps out the key enablers, sector-specific challenges, and outcomes of digital transformation, while placing deliberate emphasis on the role of Monitoring and Evaluation (M&E) as a strategic performance management mechanism. At the centre of the framework lies the core construct of digital supply chain adoption and integration, which is shaped by interrelated influences: infrastructural readiness, institutional capacity, strategic leadership, technology type, and organisational culture. These drivers either facilitate or constrain the uptake of systems such as ERP (Enterprise Resource Planning), TMS (Transport Management Systems), WMS

(Warehouse Management Systems), and emerging technologies like the IoT, blockchain, and AI.

Figure 1

Digital supply chain conceptualisation



Source: Author Construction (2025)

Enabling conditions and strategic drivers. ICT infrastructure, visionary leadership, and the need for operational efficiency emerge as critical enablers of digital transformation. As Gunasekaran et al. (2018) note, ICT capability is foundational for digital operations, while Legner et al. (2017) emphasise the centrality of leadership in directing and sustaining such transitions. In the KZN freight ecosystem, air and maritime freight operators demonstrate greater digital maturity than road freight, largely due to superior investment capacity and better access to industry-specific platforms.

Implementation barriers and sectoral challenges. Despite favourable intentions, several persistent challenges hinder digital integration. These include the high costs of implementation, resistance to change, system incompatibilities, and weak cybersecurity infrastructure. Ortwein and Kuchinke (2021) highlight the structural nature of these barriers, particularly for medium-sized operators that struggle to harmonise legacy systems with modern

technologies. These limitations also affect the pace and scale at which supply chain actors in KZN can adapt to digitalisation.

Monitoring and evaluation: Strategic feedback and institutional learning. Crucially, the integration of M&E within the framework underscores the necessity of evidence-based governance in digital transformation. The inclusion of M&E reflects an understanding that digitalisation cannot succeed on the basis of technological deployment alone, it requires a structured system of performance tracking, feedback loops, and institutional learning. As Ijeoma (2010) argues, M&E frameworks are essential for aligning performance with strategic goals. Ijeoma (2014) further maintains that in South Africa, M&E must support not only data-driven planning but also governance transparency and institutional capacity-building. The Government-wide Monitoring and Evaluation System (GWMES), developed by the South African Presidency in 2007, offers a relevant policy backdrop. It provides a unified structure grounded in Programme Performance Information, Statistics, and Evaluation, which, when adapted to freight logistics, can serve to monitor turnaround times, system availability, and intermodal coordination effectiveness.

In this framework, M&E acts as a strategic feedback mechanism, enabling decision-makers to assess whether digital interventions are yielding intended results. This resonates with Engela and Ajam (2010) as well as Rulashe and Ijeoma (2022), who caution that policy initiatives in South Africa often lack adaptability due to the absence of embedded monitoring systems. M&E addresses this gap by ensuring that system inefficiencies are identified, lessons are codified, and processes are recalibrated. Moreover, the absence of standardised M&E structures in KZN's logistics sector contributes to fragmented digital adoption and poor benchmarking. Embedding M&E within the conceptual model proposes a solution: transformation efforts must be measured, evaluated, and aligned with broader developmental outcomes. These include enhanced operational efficiency, real-time visibility, and improved governance accountability. As Masuku and Ijeoma (2015) emphasise, building M&E capacity is essential to sustain technological investments. In digital supply chains, this means developing internal evaluative expertise rather than relying solely on vendor-managed solutions. M&E thus functions as a governance enabler, ensuring that digital tools are not only operational but strategically valuable.

This conceptual model is informed by several theoretical lenses. The Technology Acceptance Model (TAM) explains user adoption dynamics, while the Diffusion of

Innovations (DoI) Theory situates the staggered uptake of technologies across sub-sectors. However, Resource Dependence Theory (RDT) is especially pertinent, highlighting the structural dependencies on infrastructure, capacity, and policy that shape digital integration outcomes. M&E, in this context, acts as a balancing mechanism that informs strategic adaptation and stakeholder coordination. This framework goes beyond mapping technology adoption to offer a reflexive and adaptive model for digital transformation. By explicitly integrating M&E, rooted in South African policy and scholarship, it ensures that freight supply chains in KZN can navigate complexity through accountability, learning, and continuous improvement.

2.3. Theoretical perspectives on Digital Supply Chain Management adoption

This study draws on four established theoretical perspectives to frame the investigation of DSCMS adoption within KwaZulu-Natal's freight sector: the TAM, Resource Dependence Theory (RDT), Transaction Cost Economics (TCE), and the DoI theory. Each theory offers a distinctive lens through which digital adoption behaviours, decision-making, and organisational dynamics can be better understood, particularly in sectors marked by infrastructural variation and operational complexity.

Table 1

Underpinning theories

Theory	Brief Discussion	Application to the Study
Technology Acceptance Model (TAM)	Developed by Davis (1989), TAM explains how users come to accept and use technology. It centres on two key beliefs: perceived usefulness and perceived ease of use.	TAM helps explain why some freight operators in KZN adopt digital systems like ERP, TMS, and WMS while others resist. Perceived complexity and uncertainty influenced uptake patterns.
Resource Dependence Theory (RDT)	RDT posits that organisations must manage external dependencies to acquire essential resources, often through strategic relationships or technology adoption.	RDT underscores the reliance of freight firms on external digital tools and vendor partnerships (e.g., CargoWise, Vessel Insight), highlighting interdependencies in the supply chain.
Transaction Cost Economics (TCE)	TCE, proposed by Williamson (1975), focuses on the costs of economic transactions, advocating for governance structures that minimise coordination and control costs.	TCE provides insight into how digital systems reduce transaction costs through automation, real-time tracking, and process integration, especially critical in maritime and air freight.
Diffusion of Innovations Theory	Introduced by Rogers (1962), this theory explains how new ideas and technologies spread through social systems, influenced by innovation attributes, time, and adopters.	This theory explains the uneven digital adoption across KZN's freight sectors. Innovators and early adopters were found primarily in large firms and the air freight sector.

Source: Zangwa Construction (2025)

The TAM, initially developed by Davis (1989), is particularly relevant to this study as it offers a behavioural explanation for how and why users adopt technological systems. In the freight context, where system complexity can be a deterrent, the model's focus on perceived usefulness and ease of use helps explain resistance among smaller logistics firms or departments with limited digital literacy. While TAM has been criticised for its limited consideration of organisational and contextual variables, its application here is useful in highlighting that digital uptake is not only a technical but also a cognitive and perceptual process. For example, several respondents expressed reluctance toward warehouse automation systems, not because they doubted their functionality, but due to uncertainty around their usability and long-term value.

As articulated by Pfeffer and Salancik (1978), RDT views organisations as dependent on external entities for critical resources. This perspective is especially pertinent to a sector like freight transport, where firms often rely on third-party providers for digital tools, data analytics, and integration platforms. In this study, RDT helps unpack how freight operators in KZN form relationships with external technology vendors, sometimes out of strategic necessity rather than choice. Such partnerships are shaped by power dynamics, cost constraints, and institutional pressures, reinforcing the idea that digitalisation in supply chains is not merely about internal readiness but also about managing interdependencies effectively.

Advanced by Williamson (1975), TCE offers yet another explanatory framework, this time by focusing on cost efficiency in organisational decision-making. From this perspective, firms are assumed to adopt digital systems when the cost of doing so is outweighed by the efficiencies they produce. This was evident in the air freight sector, where the high cost of delayed shipments and regulatory non-compliance has incentivised the adoption of automated cargo handling and real-time monitoring tools. However, the model also exposes sectoral asymmetries: in road freight, where margins are thinner, upfront investments in technology are often deferred, even if long-term efficiencies are acknowledged. TCE is particularly useful here in showing how economic rationality interacts with digital strategy.

Lastly, the DoI theory, proposed by Rogers (1962), is used to trace the patterns through which new technologies are taken up or resisted across different freight sectors. The theory identifies various adopter categories (innovators, early adopters, early majority, etc.), which were reflected in the empirical findings. Larger enterprises and firms operating in high-compliance environments (e.g., air freight) were typically early adopters, driven by the need

to remain competitive and responsive to global logistics standards. In contrast, road freight operators, particularly SMEs, tended to fall into the late majority or laggard categories, often due to limited capital, technical expertise, or exposure to peer influence. While DoI has been critiqued for overlooking structural barriers to adoption, it remains useful in this study for understanding the social and organisational factors that shape the uptake of digital systems over time.

Drawing on the TAM, RDT, TCE and DoI, tractable expectations are derived: perceived usefulness and ease of use should align with managerial support for adoption; resource interdependence with ports, carriers and regulators creates incentives for interoperable platforms; transaction risks encourage modular integration and vendor governance; and relative advantage and compatibility condition diffusion within and across firms. These expectations inform the survey constructs and the coding of interview themes reported in this paper. Taken together, these theories enrich the study's analytical depth by highlighting that digital adoption is not simply about having access to technology. It is a process influenced by perceptions, interdependencies, economic rationalities, and the broader institutional environment. The integration of these theoretical lenses enables a more holistic understanding of why digitalisation in KZN's freight sector progresses unevenly, and what might be done to address the gaps.

3. Research Design and Methodology

This research adopted a mixed-methods research design, combining both qualitative and quantitative approaches to comprehensively explore the evolution, adoption, and operational implications of DSCM systems in KwaZulu-Natal's freight transport sector. This approach was particularly appropriate, given the layered and complex nature of digitalisation, which intersects with organisational structures, technological capabilities, and behavioural practices. By integrating qualitative insights with quantitative breadth, the study captured both the lived realities of industry professionals and the broader trends shaping sectoral dynamics.

The research began with structured interviews involving 36 senior professionals from 12 logistics companies, with four from each of the road, air, and maritime freight sectors. Each firm selected three participants with extensive experience in digital supply chain implementation. The quantitative part included 36 respondents. Therefore, we primarily report descriptive statistics with scale anchors; inferential testing is limited, and we interpret findings

cautiously due to the small sample size. The modest quantitative sample limits statistical power and external validity. Future research will expand the sample to allow for more robust inferential analysis and subgroup comparisons. These interviews aimed to gather detailed accounts of digital adoption processes, institutional readiness, encountered barriers, and operational outcomes. The qualitative phase was key in revealing themes often missing from typical assessments, especially those related to context-specific challenges in a developing economy. Insights from the interviews informed the creation of a structured survey distributed to the same participants. This sequential approach ensured thematic consistency and allowed the research to examine emerging patterns and compare adoption trends across the three freight modes.

The survey included both open- and closed-ended questions and was sent electronically via Google Forms for ease of response and standardised data collection. A pilot survey was conducted first to improve question clarity and relevance, with feedback from respondents and experts helping to validate the instrument. We used a convergent mixed-methods design, conducting interviews and surveys simultaneously, analysing each separately, and then integrating the results through joint displays and narrative synthesis at the thematic level. The integration focused on convergence and complementarity; where there were differences, we explicitly report and interpret them.

Purposive sampling was employed to select individuals with at least five years of senior-level experience in freight transport operations and digital systems. This criterion was crucial in ensuring that responses were informed by practical expertise and strategic oversight. Ethical protocols, including data protection and participant confidentiality, were strictly observed in line with the Protection of Personal Information Act (POPIA). Interview data were analysed using Thematic Content Analysis (TCA), an inductive method that allowed categories and patterns to emerge organically from the data (Caulfield, 2019; Conradie, 2020). Thematic insights included institutional resistance, technical interoperability issues, sectoral disparities in digital maturity, and the operational gains attributed to technologies such as ERP, TMS, and IoT systems. These findings added conceptual depth to the framework later proposed in the study. The study integrates four lenses to structure both measures and themes. From TAM, we operationalised perceived usefulness and ease of use as Likert-type items on expected performance and usability. RDT informed items and codes on inter-organisational

interdependence, data-sharing and regulatory linkages. TCE guided attention to the asset specificity, uncertainty and governance of vendor relationships.

The DoI underpinned relative advantage, compatibility and trialability. These constructs shaped the survey item pool and the a priori nodes in the qualitative codebook, with room for inductive codes that emerged during analysis. Quantitative responses were analysed using IBM SPSS Version 29. Descriptive statistics, including frequency distributions, means, and cross-tabulations, were used to compare trends across freight sectors. This analytical approach provided a structured view of how digital systems impact operational efficiency, service delivery, and adoption readiness in the province. The chosen sample size of 36 was validated using Yamane's formula (1967, as cited in Singh & Masuku, 2014), affirming its adequacy for the study's objectives. Participants were predominantly from medium and large operators, reflecting the concentration of digital projects among firms with greater capital and compliance requirements; small and micro operators were less represented.

By synthesising qualitative depth with quantitative scope, the methodology allowed for a comprehensive and credible exploration of digital transformation in KZN's freight logistics sector, capturing both the structural realities and the strategic potential of DSCM systems. To reduce common-method and self-report bias, the survey used neutrally worded items and assured anonymity and confidentiality. Interview and survey findings were triangulated to check convergence on key patterns. Descriptive statistics are reported with scale anchors to aid interpretation. Perceptions are self-reported and may reflect social desirability or recall effects. Triangulation with interview evidence was used to moderate these risks; nevertheless, objective operational metrics would further strengthen future analyses.

4. Findings and Discussion

This section discusses and analyses the principal findings regarding the implementation and effects of DSCM systems within the freight transport sector in KZN. The data originates from qualitative interviews and quantitative surveys performed throughout the road, maritime, and aviation sectors. The analysis examines the study's aims, compares sectors, and establishes practical consequences for the freight logistics business.

Stakeholders in all sectors indicated extensive use of ERP, TMS, and WMS, along with industry-specific solutions such as Vessel Insight for maritime and CargoWise for air freight. These systems have typically been established for 3 to 10 years, motivated by objectives such

as enhancing operational efficiency, transparency, and regulatory compliance. As one maritime logistics executive explained: *"Our implementation of Vessel Insight has not only improved our route planning but has allowed for real-time coordination with port authorities, which was previously a major bottleneck."*

Table 2

Sector-specific digital SCM systems

Sector	Core Systems	Unique Technologies
Maritime	ERP, TMS, IoT, Real-time Tracking	Vessel Insight, ShipServ, VTMIS
Road	ERP, TMS, WMS	AI-enabled Routing Systems
Air	SAP TM, WMS, ERP	CargoWise, CargoSpot

Of the 36 participants, 91.7% recognised cost savings and service enhancement as primary motivators of digitisation. A substantial percentage (58.3%) identified digitalisation as the foremost objective in intelligent transport systems, followed by logistics (38.9%). The mean rating for "operational efficiency improvement" across all participants was 4.6 on a 5-point Likert scale (SD = 0.43), indicating strong agreement that DSCM adoption has enhanced productivity. Real-time monitoring and enhanced decision-making were emphasised as fundamental advantages. An air freight respondent noted, *"With CargoWise, we now make routing decisions in seconds rather than hours. The visibility it gives us into cargo movement is unmatched."* Challenges in adoption encompass elevated expenses, reluctance to change, integration difficulties, and cybersecurity risks. A road freight manager remarked, *"Our biggest hurdle is not the technology itself, but the people. There's a fear that automation will replace jobs, and that slows down adoption."*

Table 3

Top drivers of digitalisation

Drivers of digitisation	Frequency	Percentage
Cost reduction and service level improvement	33	91.7%
Reduce damage/safety improvement	28	77.8%
Process control and monitoring enhancement of business processes	29	80.6%
Traceability and visibility	27	75%
Efficiency and effectiveness	31	86.1%
Competitiveness	27	75%

The results of this study resonate with the findings of Conradie (2020), affirming the utility of thematic coding in distilling meaningful stakeholder insights across sectors. Emerging technologies such as AI, IoT, and blockchain were consistently identified by participants as transformative forces shaping the future of freight logistics. In line with global patterns, these technologies are not only perceived as innovative but as critical enablers of operational agility, transparency, and competitiveness within the regional supply chain landscape. Sector-specific findings further reflect the differentiated adoption trajectories across modes. The maritime sector demonstrated extensive engagement with DSCM tools, consistent with the global literature that links seaborne logistics to heightened regulatory compliance and system sophistication. In contrast, the aviation sector exhibited strong emphasis on speed, visibility, and precision, underpinned by widespread adoption of integrated platforms such as SAP Transportation Management (SAP TM) and CargoWise. The road freight sector, while comparatively less digitised, prioritised routing efficiency, cost optimisation, and basic logistical coordination areas, where ERP and TMS systems were particularly instrumental.

The study's objectives were systematically addressed. Firstly, the identification of DSCM systems was accomplished through detailed sectoral mapping. Across all sectors, core platforms such as ERP, TMS, and WMS were in use, supplemented by mode-specific solutions tailored to operational nuances. Secondly, the operational impacts of these systems were clearly evident. Qualitative feedback highlighted reductions in manual paperwork and enhanced inventory accuracy, while quantitative data reflected strong perceived advantages, with mean scores exceeding 4.3 on key performance indicators. For instance, one logistics coordinator shared, *"What used to take two days in paperwork now takes 30 minutes through our integrated ERP system. It's a game-changer."* Thirdly, implementation challenges emerged as a critical concern. Resistance to organisational change, difficulties integrating new technologies with legacy systems, and cybersecurity concerns were consistently reported. Participants emphasised the importance of phased implementation strategies and sustained capacity-building efforts to mitigate these barriers. Lastly, the study confirmed significant sectoral variation in digital maturity. Air freight was found to be the most advanced in terms of technological uptake, followed by the maritime sector, with the road freight sector showing incremental but uneven progress. Survey results showed that 78% of air freight respondents reported "high" or "very high" satisfaction with their current DSCM platforms, compared to 64% in maritime and 52% in road transport. These distinctions underscore the need for

differentiated policy and operational strategies tailored to each freight mode's digital readiness and institutional constraints.

The thematic analysis distilled rich insights from stakeholders across KZN's freight transport sectors, maritime, air, and road, revealing nuanced differences in digital system adoption, operational impact, sector-specific challenges, and emerging technological trajectories. In terms of system adoption, the maritime sector emerged as the most technologically diversified, deploying a broad suite of systems including Port Management Information Systems (PMIS), Vessel Traffic Management Information Systems (VTMIS), and Terminal Operating Systems (TOS). This maturity contrasts with the air freight sector, where the focus lies on precision-enhancing technologies such as real-time cargo tracking and automated inventory systems. Meanwhile, the road freight sector demonstrates a pragmatic orientation, prioritising logistics optimisation through fleet management tools and WMS.

Operationally, the integration of digital technologies across all three sectors yielded consistent benefits, improved visibility, real-time decision-making, and enhanced transparency. Notably, road freight companies reported optimised route planning and reduced fuel expenditure, while air freight stakeholders highlighted gains in inventory accuracy and regulatory compliance. A transport operations director in the road sector noted, *"Using our AI-powered routing tool, we've cut fuel costs by 12% in the past year alone."* Maritime firms valued the synchronisation of port operations and reduced turnaround times (Table 4). These improvements align with global trends, which suggest that digitalisation catalyses process agility and stakeholder collaboration (Ageron et al., 2020; Queiroz et al., 2022).

Table 4

Common challenges and mitigation strategies

Challenge	Sectors Affected	Mitigation Strategies
Resistance to change	All	Training, Change Management
System integration	All	Middleware, Phased Implementation
Cybersecurity	Maritime, Air	Robust Security Measures
High initial costs	All	Phased Investment, External Funding

However, challenges to digital transformation remain persistent. Across all sectors, respondents cited resistance to change, high implementation costs, and complex system integration as significant barriers. These findings are consistent with previous literature, which

underscores the need for supportive change management strategies and alignment between technological investments and organisational readiness (Nowicka, 2019; Mashalah et al., 2022). Looking ahead, stakeholders across the freight industry anticipate a more pervasive role for AI, blockchain, and the Internet of Things (IoT). Maritime respondents forecast increased reliance on autonomous vessel systems; road freight anticipates the growth of drone-based delivery and predictive route optimisation; and air freight expects greater automation in cargo handling and safety compliance.

From a policy perspective, the findings underscore the necessity for structured public-private collaboration to strengthen digital infrastructure, particularly in cybersecurity and system interoperability. The comparative variations in digital maturity across sectors highlight the need for targeted investment strategies that reflect sector-specific readiness and constraints. Gcezengana et al. (2022) and Sidiya et al. (2022) argue that deliberate, well-designed training and development for public officials is a high-return investment that strengthens administrative capability and, in turn, improves the efficiency and effectiveness of public service delivery. On the operational front, structured digital upskilling programmes and capacity-building initiatives, especially those informed by the Public Service SETA and Transport Education and Training Authority (TETA), are recommended. These initiatives should prioritise leadership development and change resilience, which are often overlooked in digital transformation strategies. Moreover, investment priorities should reflect sectoral needs: autonomous navigation systems in maritime logistics, AI-based last-mile delivery solutions for road transport, and integrated automation systems for air freight.

Maritime sector: While digitally advanced, this sector requires urgent attention to cybersecurity and data integrity protocols, especially in view of its reliance on interconnected port systems.

Road sector: Investments should focus on AI-driven logistics and mobile platform integration to enhance routing efficiency and cost savings.

Air sector: With high regulatory demands, this sector would benefit from improved data interoperability and automation in compliance reporting and cargo tracking.

The implementation of DSCM systems across KZN's freight sectors is demonstrably advancing, though progress remains uneven. Strategic, sector-tailored investments and cross-sector collaboration are vital to consolidate these gains. The successful diffusion of digital technologies will depend on balancing innovation with readiness, as well as fostering a culture

of adaptive learning. Ultimately, digital transformation must be seen not as a technological upgrade, but as a systemic shift that aligns organisational processes, workforce competencies, and governance structures to the demands of a digitally connected global logistics landscape.

Proposed Normative Model for Digitalised Freight Systems

This study proposes a normative model to facilitate the optimal implementation of DSCM across the air, sea and road freight industries in KZN, addressing operational inefficiencies, integration challenges, and disparities in technology adoption identified in the freight transport sectors. Utilising normative decision theory (Varian, 1992; French & Ríos Insua, 2000), the model provides a prescriptive framework detailing optimal practices, suggested technologies, incremental adoption techniques, operational consequences, and enduring technological pathways.

Utilisation of technology. The approach underscores the use of fundamental technologies such as ERP, TMS, WMS, blockchain, IoT, real-time tracking, and industry-specific solutions like Vessel Insight for maritime, CargoWise for air, and sophisticated routing tools for road transport. RFID and AI-based technologies are advocated for air freight to enhance tracking and operational accuracy. These technologies correspond with prevailing global trends in goods digitisation that emphasise integration, transparency, and data-driven decision-making (Bichou, 2009).

Adoption strategy. A phased implementation strategy over a three- to five-year period is recommended, enabling sectors to progressively address integration challenges and financial investments. Prioritise IoT and tracking technologies, then focus on blockchain, AI, and ERP improvements. This reflects the frameworks suggested by Queiroz et al. (2022), which promote gradual implementation to alleviate organisational resistance and financial limitations.

Operational consequences. The model predicts enhancements in real-time visibility, operational efficiency, inventory precision, and cost savings. Sea freight advantages include less paperwork and improved port administration; road freight offers superior routing and delivery timelines; air freight enhances inventory management and minimises errors. These assumptions correspond with empirical evidence about the benefits of DSCM in multimodal logistics contexts (Notteboom et al., 2021).

Ongoing enhancement and future orientation. The model recommends ongoing investment in AI-driven predictive analytics, automation, and sustainable logistics techniques

to sustain competitiveness. Unmanned vessels and renewable energy technologies are emphasised in maritime freight. Road freight should prioritise predictive maintenance and blockchain-based tracking, whereas air freight ought to explore enhanced automation and integrated data systems.

Challenge prevention. Recognising obstacles including cybersecurity threats, integration difficulties, and substantial implementation expenses, the model advocates for extensive change management strategies, gradual rollouts, cybersecurity protocols, and thorough training programs. These solutions embody current guidelines for mitigating risks associated with digital transformation in transport and logistics (PwC, 2022; Lopez Conde & Ashley, 2023).

Benchmarking and comparative evaluation. The methodology facilitates the identification of enhancement possibilities through cross-sector benchmarking with global best practices. Maritime sectors ought to evaluate port management and tracking systems against premier worldwide operators; road freight should implement routing and operational strategies from leading logistics companies; and air freight should examine sophisticated security and cargo monitoring systems.

Innovative technologies. The model recognises AI, IoT, blockchain, and 5G as essential technologies for the invention of future goods systems. It further emphasises sector-specific opportunities: green shipping and autonomous vessels in marine, drone-assisted last-mile delivery and big data analytics in road transport, and robotics-enhanced cargo handling in air freight (Queiroz et al., 2022).

5. Conclusion

The study examines how digital supply chain management systems (DSCMS) are being implemented and experienced across the road, maritime, and air freight sectors in KwaZulu-Natal (KZN), South Africa. The findings, drawn from a mix of qualitative and quantitative methods, paint a detailed and compelling picture of how digitalisation is gradually reshaping the freight transport landscape in this region. One of the key observations from the research is that adoption levels of digital systems such as ERP, TMS, WMS, Vessel Insight, and CargoWise were noticeably higher among larger, more established companies. These firms reported meaningful gains in areas like inventory accuracy, order turnaround times, and real-

time decision-making, much of which stemmed from better visibility and integration across their logistics operations.

Despite these advances, the transition to digital systems has not been without obstacles. As one executive put it, *"The benefits are clear, but we're flying the plane while building it. The transition has to be carefully managed, or it could backfire."* Across the board, participants spoke of common challenges: the difficulty of integrating new technologies with older systems, high costs at the outset, resistance from within organisations, and growing concerns about cybersecurity, especially in data-heavy sectors like maritime and air freight. Encouragingly, many had found ways to respond to these difficulties, opting for phased rollouts, investing in employee training, and using integration tools such as middleware to bridge system gaps. Stronger cybersecurity protocols were also being introduced, although concerns persist in some areas. Each sector brought its own digital profile to the fore. Maritime operations placed emphasis on global oversight and environmental responsibility, although they remain vulnerable to cyber threats. Road freight companies, on the other hand, focused more on improving last-mile delivery and routing systems. The air freight sector was found to be the most technologically advanced overall, with notable investment in automation and regulatory compliance. Across all three sectors, there was clear anticipation that technologies such as artificial intelligence, machine learning, IoT, blockchain, and sustainable logistics tools will shape the next wave of supply chain innovation over the coming decade.

Beyond the empirical results, the study makes several contributions to the broader conversation on supply chain digitalisation. It offers a rare comparative view of how digital tools are being adopted within and across specific freight sectors, something that is often glossed over in existing literature. The research also brings practical value by identifying workable solutions to known challenges and framing digitalisation as a long-term strategy for competitiveness, sustainability, and resilience, not simply a short-term operational fix. That said, the study has some limitations. Because it focused solely on KZN, the findings may not fully reflect the realities of other provinces or international freight environments. There are also potential gaps in the sample, particularly if smaller firms or less formal operations were underrepresented. Given the pace at which digital technology evolves, some of the findings, especially those related to specific tools or systems may become less relevant over time. And finally, since much of the data came from self-reported responses, there is always a risk of bias or subjectivity in how experiences and outcomes were described.

Looking ahead, there is room for further research. Longitudinal studies would help track how digital adoption changes over time and whether the initial benefits hold. Comparative studies both within South Africa and across international settings could offer a clearer sense of how regional factors influence the success of digital supply chain initiatives. There is also a need to look more closely at individual technologies, such as blockchain or AI, and assess how they contribute to resilience and sustainability. The human side of digital transformation warrants more attention too, particularly how workers adapt to change and how effective training and organisational culture are in supporting that shift. On a practical level, there are several steps that freight companies and policymakers can take. Investing in adaptable, interoperable digital tools is key to systems that can evolve as business needs change. There's also a strong case for improving collaboration, particularly through shared data platforms that allow different actors in the supply chain to coordinate more effectively. Public-private partnerships could play a vital role in bridging the gap between logistics operators and technology providers, ensuring that solutions are not only technically sound but also affordable and fit for purpose.

Finally, the push for greener, more sustainable logistics needs to be a priority. As companies invest in digital systems, environmental goals should not be an afterthought but an integral part of the innovation agenda. In sum, the digital transformation of KZN's freight sector is progressing, though unevenly. To harness its full value, digitalisation must be approached not as a one-off project, but as a broader strategic shift, one that aligns people, processes, and technology. The analysis centres on one provincial ecosystem. While KZN is a major freight hub, institutional arrangements and capability profiles vary across provinces. Generalisability is therefore limited; comparative studies across provinces and corridors are a clear next step. Because small and micro enterprises were under-represented, some constraints unique to SMEs (capital constraints, vendor lock-in, and limited digital support) may be understated. Future work should purposively sample SMEs and owner-drivers to surface tailored pathways for adoption. The future of freight in South Africa depends not just on whether companies adopt digital systems, but on how thoughtfully and inclusively that transformation unfolds.

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Institutional Review Board Statement

This study was conducted in accordance with the ethical guidelines set by Durban University of Technology (DUT). The conduct of this study has been approved and given relative clearance(s) -Ethical Clearance Number (181/22) by Durban University of Technology (DUT).

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