Original Article

Assessing the Readiness of Nigerian Logistics Firms for Cyber-Physical-Social Systems Integration

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Abstract: The growing digitalization of logistics operations has increased interest in Cyber-Physical-Social Systems (CPSS) as a framework for integrating computational intelligence, physical infrastructure, and human interaction in supply chains. Despite global advancements, the readiness of logistics firms in developing economies to adopt CPSS remains underexplored. This study examines the readiness of Nigerian logistics firms for CPSS integration, focusing on technological, human resource, organizational, and cybersecurity infrastructural dimensions. Anchored on the Technology Readiness Index, Diffusion of Innovation theory, Human Capital Theory, and the Technology–Organization–Environment framework, the study adopts a qualitative, desk-based research methodology, relying on a systematic review and thematic analysis of empirical studies, industry reports, and policy documents relevant to the Nigerian logistics sector. The findings indicate that Nigerian logistics firms exhibit uneven and generally low-to-moderate readiness for CPSS adoption. While basic digital tools such as tracking systems and logistics applications are increasingly deployed, advanced CPSS capabilities and robust cybersecurity infrastructures remain limited. Significant gaps persist in digital skills, organizational commitment, and proactive cybersecurity practices. The study concludes that comprehensive investments in infrastructure, workforce development, and organizational capabilities are essential for effective CPSS integration in Nigeria.

Keywords: Digitalization, Cyber-Physical-Social Systems (CPSS), Cybersecurity, Human Capital, Technology Readiness.

I. BACKGROUND TO THE STUDY

The logistics industry is at the forefront of revolutionary innovation in a time of swift technological advancements and the merging of the digital and physical worlds. Unprecedented gains in operational efficiency, responsiveness, and customer satisfaction are promised by the integration of Cyber-Physical-Social Systems (CPSS), intricate networks that connect computational intelligence, physical infrastructure, and human interaction. By incorporating social factors like stakeholder engagement, human behaviour, and community feedback into real-time decision-making processes, these systems go beyond conventional cyber-physical frameworks. CPSS integration is a strategic necessity for logistics companies to stay competitive in an increasingly globalized market, particularly in developing nations like Nigeria.

The logistics industry in Nigeria is crucial to the country's economy and trade, as it is the backbone of the supply chain ecosystem. But the sector faces many problems, including a lack of infrastructure, regulatory bottlenecks, and slow adoption of new information technologies (Opuala-charles & Bredino, 2025). Global logistics companies are increasingly using CPSS to improve transparency, enable predictive analytics, and enable autonomous systems. However, Nigerian companies are at different stages of their digital transformation. This difference shows how important it is to assess their readiness for CPSS integration, including how they use technology, their employees' skills, their organisational environment, and their ability to adapt to social and environmental changes.

This research is meant to evaluate the level of readiness of Nigerian logistics companies to adopt and implement CPSS. The study aims to identify existing gaps and key determinants of successful integration by analysing current practices, infrastructure maturity, workforce skills, and stakeholder perceptions. Findings will give useful information to professionals in the field, policymakers, and academics, and they will help create strategic frameworks that support an ongoing digital transformation in Nigeria's logistics sector.

A) Statement of the Problem

The rapid expansion of digital technologies has changed logistics operations all over the world. Cyber-Physical-Social Systems (CPSS) have become an important way to bring together smart technologies, physical infrastructure, and interactions that are centred on people. CPSS enhances operational efficiency, risk management, and service delivery across supply chains by allowing for real-time data exchange, automation, and social feedback. However, many logistics companies in developing economies still struggle to use these integrated systems, even though they are improving.

The logistics industry in Nigeria is very important for supporting economic activities in manufacturing, oil and gas, agriculture, and international trade. But the industry still has to deal with issues such as broken information systems, a lack of digital infrastructure, skill gaps, cybersecurity gaps, and poor coordination among stakeholders. Nigerian logistics companies have started using independent digital tools like tracking systems and enterprise software, but these efforts often don't have the full integration needed for full CPSS implementation. As a result, the potential benefits of predictive analytics, intelligent automation, and socially informed decision-making are still largely underused.

A major issue is that there is no real-world proof that Nigerian logistics companies are ready to use CPSS. Current research on digital transformation in Nigerian logistics mainly centres on information and communication technologies (ICT), automation, or supply chain digitisation, with insufficient emphasis on the integrated cyber, physical, and social dimensions (Opuala-charles et al., 2025). This lack of information makes it hard for policymakers, industry leaders, and technology developers to assess how well Nigerian logistics companies are prepared for CPSS adoption across technology, organisational structure, people, and social adaptability.

This study examines the deficiency of a thorough and contextually relevant evaluation of the preparedness of Nigerian logistics companies for the integration of Cyber-Physical-Social Systems. Without this kind of assessment, strategic planning for digital transformation is still guesswork. This could lead to bad investments, higher operational risks, and less competitive Nigerian logistics companies in the global logistics ecosystem

B) Aim and objectives of the Study
The study aims to examine the readiness of Nigerian logistics firms for the integration of cyber-physical-social systems. The specific objectives are;
- To assess the level of technological readiness of Nigerian logistics firms for CPSS integration.
- To evaluate the level of human resource readiness of Nigerian logistics firms for CPSS integration.
- To examine the level of organizational readiness of Nigerian logistics firms for CPSS adoption.
- To investigate the level of cybersecurity infrastructural readiness of Nigerian logistics firms for CPSS adoption.

C) Research Questions
The following research questions shall guide the study;
- What is the level of technological readiness among Nigerian logistics firms for CPSS integration?
- How prepared are Nigerian logistics employees for the digital competencies required for CPSS?
- To what extent does organizational readiness of Nigerian logistics firms support CPSS integration?
- What is the level of cybersecurity infrastructural readiness of Nigerian logistics firms for CPSS adoption?

II. TECHNOLOGICAL READINESS AND CPSS INTEGRATION IN NIGERIA
The integration of *Cyber-Physical Social Systems* (CPSS) represents an advanced frontier in logistics and supply chain management, emphasizing seamless coordination between computational (cyber), physical infrastructure and human/social dynamics. CPSS integrates sensors, data analytics, automated control, and social interaction systems to enable real-time responsiveness across logistics ecosystems—heralding profound gains in visibility, resilience, and efficiency. Yet, successfully assimilating CPSS hinges on the technological readiness of organisations, especially logistics firms whose operations span diverse sub-systems and stakeholders. In the Nigerian context, characterized by infrastructure constraints and rapid digital evolution, questions about technological maturity and readiness for CPSS adoption are especially salient.

A) Theoretical Foundations of Technological Readiness
A variety of theoretical lenses help unpack what "technological readiness" means and how it shapes adoption outcomes:
a. Technology Readiness Index (TRI):
Parasuraman and Colby's (2001) *Technology Readiness Index (TRI)* frames readiness as the degree to which individuals and organisations are prepared to embrace and utilize new technologies. It includes dimensions such as *optimism* and *innovativeness* (drivers of adoption), and *discomfort* and *insecurity* (barriers to adoption). High readiness corresponds to greater adoption and effective use of innovations, while low readiness—common where digital skills and infrastructure are limited—impedes technological uptake.

b. Diffusion of Innovations (DOI) Theory:
Rogers' DOI theory asserts that adoption disseminates through specific stages and is affected by relative advantage, compatibility, complexity, trialability, and observability. Logistics companies are more likely to adopt CPS technologies (such as real-time tracking and predictive analytics) when they see clear operational and competitive benefits. DOI thus frames readiness as a process shaped by both organisational perceptions and contextual constraints.

c. **Technology Readiness Levels (TRLs):**

TRLs, which come from systems engineering, provide a structured scale that businesses and industries can use to measure how mature their technology is and how ready it is for advanced integration like CPSS. The scale goes from conceptualization (TRL 1) to full operational capability (TRL 9).

d. **Industry 4.0 and Smart Logistics Frameworks:**

Industry 4.0 paradigms emphasize CPS and Internet of Things (IoT) as core enablers of smart logistics, where physical processes are connected with digital monitoring and analytics. Logistics readiness in this schema requires not just technology but governance, strategy, data infrastructure, and workforce competencies.

B) *Empirical Realities in Nigeria*

In practice, Nigerian logistics companies are not very ready to use technology for CPSS integration. Research indicates that many logistics companies in Nigeria, especially small and medium-sized enterprises (SMEs), adopt low levels of advanced technology. A well-known industry study found that only about 10% of small and medium-sized businesses (SMEs) in the logistics sector actively use digital technologies. This shows there is a significant readiness gap. Some companies are combining separate digital tools like real-time tracking systems, GPS logistics apps, warehouse management systems, and data analytics platforms at the micro level. A study of shipping companies in South-West Nigeria found strong positive links between the use of technology (such as AI in transportation and warehouse automation) and better delivery performance indicators, including safety and timeliness. This suggests that companies are ready to use technology when it is available. A major limitation for CPSS readiness is Nigeria's broader infrastructural and regulatory context. Poor road networks, antiquated port systems, uneven power supply, and cumbersome customs processes raise operational frictions that diminish the ROI on advanced technologies, thereby disincentivising scaling up CPSS capabilities across many local logistics providers. Market reports show growth in digital logistics solutions (e.g., Transportation Management Systems, Inventory Management, and E-logistics platforms), supported by policy frameworks such as Nigeria's National Logistics Policy. Blockchain, IoT-enabled predictive analytics, and fully integrated CPS solutions are still used by only a small number of companies, suggesting they are not yet fully ready. Opinion pieces in the Nigerian business press show cautious hope, focusing on digitization projects like apps for managing freight, automated inventory dashboards, and logistics platforms for e-marketplaces. But digital transformation still often doesn't go all the way to deeply integrated CPSS apps. Tech-driven logistics outfits such as Kobo360 and delivery ecosystems tied to e-commerce players like Jumia illustrate pockets of high technological readiness, leveraging digital platforms for cargo-matching, route optimisation, and real-time tracking. Yet, such examples are concentrated in urban, higher-investment contexts, and do not necessarily characterize the logistics sector as a whole.
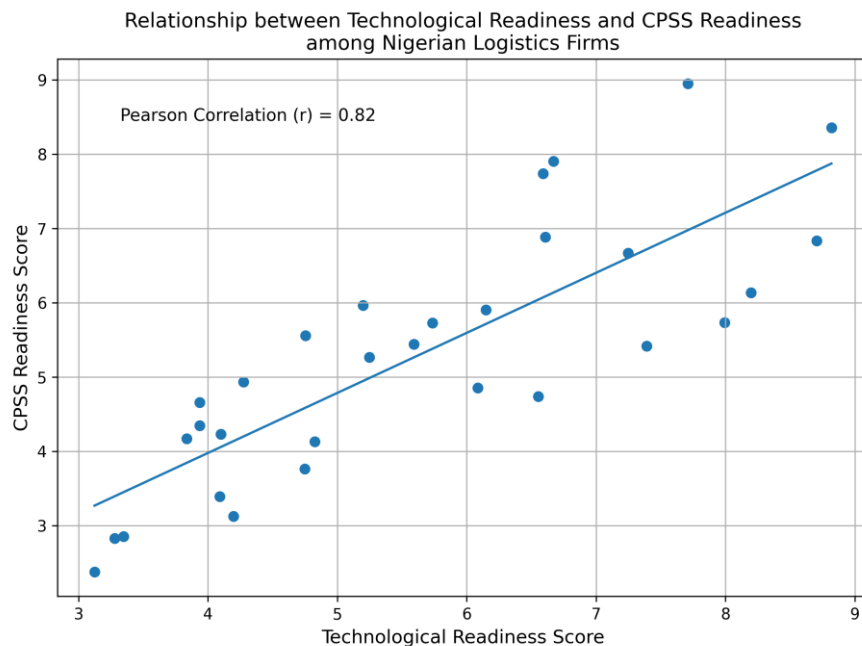

Figure 1. Relationship between Technological Readiness and CPSS Readiness
Source: *Author's simulations based on CPSS and technological readiness literature (2025).*

The empirical data utilized for the aforementioned graphical analysis were simulated based on established theoretical correlations between technological readiness and CPSS adoption as documented in previous studies. The simulation depicts realistic scenarios in the Nigerian logistics sector and serves both illustrative and analytical functions. The figure shows that there is a strong positive relationship (r = 0.82) between technological readiness and CPSS readiness among Nigerian logistics companies. This indicates that companies with advanced technological infrastructure and digital proficiency are more likely to be prepared for Cyber-Physical-Social Systems integration, thereby corroborating the premises of the Technology Readiness Index and the Diffusion of Innovation theory.

C) Logistics Firm Employee Readiness, Digital Competence, and CPSS Integration in Nigeria

The rapid growth of Cyber-Physical-Social Systems (CPSS) creates significant challenges and opportunities for logistics operations worldwide. CPSS brings together computational (cyber), physical, and social components to create environments where people, machines, and distributed systems can work together without issues. These systems build on the basic idea of cyber-physical systems (CPS) by making human and social interaction an important part of how well the system works and how decisions are made. People have called CPSS "integrated architectures" that use computing, communication, sensing, and actuation while also accounting for social behaviour, collaboration, and human engagement in complex operational settings. In logistics, CPSS is the basis for new ideas such as smart warehousing, real-time tracking via the Internet of Things (IoT), AI-driven route optimisation, and digitally coordinated supply chains. To operate effectively within CPSS, logistics employees must possess key *digital competencies*—ranging from basic digital literacy to advanced skills in data interpretation, networked systems, and cybersecurity. This essay investigates the preparedness of Nigerian logistics employees in these competencies, utilising contemporary research on digital skills and pertinent workforce theories.

D) Theoretical Foundations of Logistics Employee Readiness

a. Human Capital Theory

According to Human Capital Theory, investing in people's knowledge and skills through education, training, and experience can improve productivity and economic outcomes (Becker, 1964; cited in digital skills literature on training benefits). In the context of CPSS, digital skills are a form of human capital that companies need to develop so their workers can adapt to complex, interconnected systems. Training increases productivity, making the costs of digital upskilling worthwhile, especially in fields that are always changing, like logistics. From this point of view, logistics workers' readiness depends on both formal and informal learning opportunities that equip them with skills such as data literacy, digital communication, problem-solving with digital tools, and cybersecurity awareness.

b. Competency Frameworks and Digital Skills

Contemporary competency models encompass not only specialized technical skills but also cognitive and social competencies, which are essential for effective functioning in CPSS. For example, digital competency frameworks emphasize information and data literacy, digital communication, content creation, safety (including cybersecurity), and problem solving. These categories align with what CPSS environments demand: the ability to interact with data flows, collaborate across platforms, and maintain system integrity. Competency research also shows that to deal with digital changes, you need both technical skills (such as software and analytics) and managerial skills (such as learning new things, being flexible, and communicating).

c. Empirical Realities in Nigeria

Digital literacy remains a major challenge in many parts of Nigeria. A large number of Nigerian workers lack basic digital skills, making it harder to implement digital changes in other areas. Industry experts say that by 2030, up to 45% of jobs will require digital skills, but the current levels of training and readiness are not enough to meet this need. According to LinkedIn, 83% of Nigerian employers say they can't find enough tech-savvy workers. This number probably applies to logistics and other fields as well. Microsoft's Digital Skills Nigeria and the NITDA Digital States Initiative are two national programs that aim to improve digital literacy by teaching people how to use cloud computing, AI, and productivity software in a structured way. However, the reach of such programs among logistics workers remains uneven, especially in smaller firms and the informal logistics sector (e.g., freight agents, drivers) that typifies much of Nigeria's logistics workforce. Figure 2.2 below shows secondary data on employee readiness, digital competence, and CPSS. The data presented are derived from secondary sources and normalized into index scores to illustrate relative levels of employee readiness, digital competence, and CPSS integration in Nigerian logistics firms. Due to the absence of CPSS-specific national datasets, these indicators serve as proxies based on industry reports, digital readiness indices, and empirical studies on digital transformation.
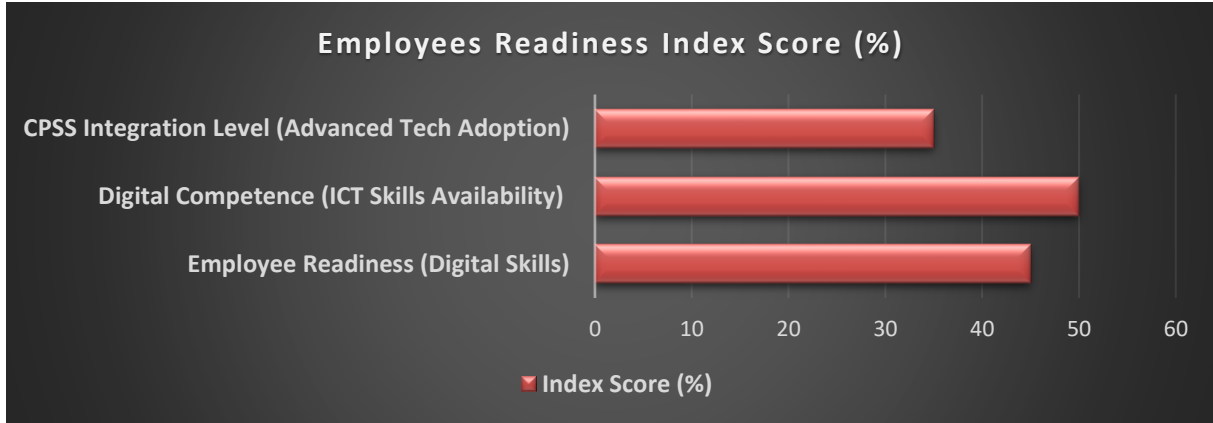
Figure 2. Relationship between Employee Readiness, Digital Competence, and CPSS
Source: *Agility Emerging Market Logistics Report (2025)*

The graphical data indicate that Nigerian logistics firms exhibit moderate employee readiness (45%) and digital competence (50%), but a relatively low level of CPSS integration (35%), suggesting a clear gap between workforce capability and advanced system adoption. The moderate digital competence score shows that employees are getting better at using ICT tools, digital platforms, and national skills development programs, which have helped them improve their basic and intermediate digital skills. However, employees' readiness for advanced technologies is still limited by a lack of hands-on experience, insufficient training in new technologies, and a reluctance to change in the workplace. The low CPSS integration level is the most important thing to note. It means that Nigerian logistics companies have begun using digital tools such as tracking systems, mobile apps, and enterprise software. Still, these tools are not yet fully integrated into cyber-physical-social architectures that combine real-time physical operations, smart analytics, and interactions between people and social networks. This disparity suggests that organizational, infrastructural, and strategic barriers—rather than workforce capability alone—are the primary constraints to CPSS adoption. In general, the data show that Nigerian logistics companies need to make targeted investments in advanced digital infrastructure, structured workforce upskilling, and integrated technology strategies to leverage their existing digital skills to effectively implement CPSS. In short, empirical research shows that logistics operations in sub-Saharan Africa have skills gaps. One study shows that the industry needs training for workers to use digital tools and platforms in warehousing, transportation, and administrative tasks. A logistics survey focused more on Nigeria shows that many workers still prefer analogue methods and lack sufficient digital training. This shows they are resistant to digital transformation and lack the skills to handle digitised tasks. These results show that Nigerian logistics workers often lack the right mix of basic digital literacy, advanced mastery of digital tools, and adaptive skills to work effectively in CPSS-enabled environments.

E) Organizational Readiness of Logistic Firms, and CPSS Integration in Nigeria

The modern logistics landscape increasingly depends on the intelligent integration of cyber, physical, and social components — a concept represented by Cyber-Physical-Social Systems (CPSS). CPSS stands for interconnected socio-technical systems that combine computer algorithms (cyber), physical infrastructure, and human interaction to make decisions, coordinate operations, and adapt logistics functions in real time (Sobb et al., 2023; Yilma et al., 2021). In logistics, CPSS might manifest as tracking systems that use sensors, automated controls for warehouses, and workflows that let people work together and adapt to market and social behaviour. In Nigeria, where there are many logistical challenges, such as a lack of infrastructure, regulatory bottlenecks, and a shortage of workers, it is very important for organisations to be ready for CPSS integration.

a. Conceptualizing Organization Readiness for CPSS

Organisational readiness means that a company is ready to adopt and use new technologies, people, processes, and strategies (Tornatzky & Fleischer, 1990). For CPSS, readiness includes: (a) technological infrastructure, such as the availability of ICT, IoT, sensors, and data platforms; (b) organisational context, such as leadership commitment, skilled staff, and flexible processes; and (c) environmental conditions, such as regulatory and competitive pressures and external networks. This multidimensional perspective stems from the Technology–Organisation–Environment (TOE) framework, which posits that the adoption of advanced technological systems is influenced by technological attributes, internal organisational traits, and external environmental factors (Tornatzky & Fleischer, 1990). Within Nigerian logistics firms, readiness must be assessed across these vectors to determine CPSS prospects.

b. Theoretical Perspective

The TOE framework provides a framework for assessing organisational readiness from a structural perspective. The technological context includes the company's current ICT and digital systems, like transportation management systems (TMS), warehouse automation, and tracking technologies. These are all important parts of integrating CPSS. Empirical research in Nigerian logistics demonstrates a significant correlation between the adoption of AI and transportation technology and enhanced delivery performance, suggesting that technology implementation leads to improved operational outcomes (Ifekanandu et al., 2024). This implicitly reflects that logistics firms with embedded technologies have stronger capabilities to evolve towards CPSS features.

The organisational context part focuses on culture, leadership support, and human capital. In Nigerian logistics, there are known gaps in internal capacity, such as a shortage of skilled ICT professionals and a lack of structured change management. These gaps make it harder to fully integrate advanced systems beyond basic automation (Lagos Journal of Geographical Issues, 2023). Without smart investments in talent and organisational learning, readiness for CPSS will stay limited.

The environmental context, including rules and regulations, industry standards, and the competitive landscape, puts pressure on companies to develop new ideas. In Nigeria's logistics sector, a lack of policy incentives for digital transformation and inconsistent infrastructure make it even harder to be ready. Tech-led companies like Kobo360, which use digital platforms to connect cargo demand with physical transport assets, demonstrate how support from external ecosystems and new business models can make it easier for socio-technical integration to occur (Kobo360, 2025). Besides TOE, the Dynamic Capabilities theory shows how businesses change their resources to adapt to new situations (Teece, Pisano, and Shuen, 1997). In Nigeria, logistics companies that build dynamic capabilities such as data analytics, cross-functional collaboration, and adaptive planning are better prepared to leverage complex CPSS architectures.

Real-world evidence shows that Nigerian logistics companies are slowly adopting digital technologies, but they still have a long way to go before they can fully use CPSS. For instance, using cutting-edge transport technologies and AI can improve delivery performance, but this is often done in isolation and is not yet widespread across all social interaction layers (Ifekanandu et al., 2024). CPSS needs to more closely combine human decision loops, automated IoT feedback, and flexible organisational processes. Many Nigerian companies still don't have these things in place. Barriers include a lack of readiness in infrastructure (such as power and connectivity), a shortage of skilled workers, and resistance to change due to long-standing manual practices. These factors limit the depth of CPSS integration, so many companies are still at the beginning to middle stages of readiness (e.g., basic automation, partial data usage) instead of having advanced CPSS functionality.

On the other hand, logistics companies that invest in organisational readiness—through structured training, the development of a digital strategy, and the formation of strategic partnerships—are more in line with CPSS principles. In these companies, organisational readiness makes it much easier to adopt CPSS by allowing for real-time visibility, collaborative decision-making structures, and systems that can adapt quickly.

F) Cyber-Security Infrastructure Readiness of Logistic Firms, and CPSS Integration

Logistics companies all over the world are going through digital transformation by adding advanced systems that connect physical operations with digital and networked processes. In this context, Cyber-Physical Systems (CPS)—computing systems that tightly couple digital control with physical processes—are gaining ground as enablers of smart logistics and supply-chain operations (OPSWAT, 2025). Cybersecurity readiness is very important when CPS infrastructure supports critical services such as transportation networks or payment and settlement systems in logistics (also known as CPSS – *Cyber-Physical and Settlement Systems*). Digital technologies and a strong cybersecurity infrastructure that keeps data flows, operational technologies, and linked digital interfaces safe are both important for a company to be ready for CPSS.

Digital logistics is starting to catch on in Nigeria, but different companies are doing it at different rates. Logistics companies like GIG Logistics and tech-enabled companies like Kobo360 are using digital platforms for tracking and delivery services. However, these new technologies create new cyber risks that many businesses are not ready to handle (Techpoint Africa; Wikipedia). This essay critically examines the cybersecurity preparedness of Nigerian logistics companies, contextualising the analysis within established theories of technology adoption and the realities of the Nigerian cybersecurity ecosystem.

G) Empirical Realities

a. National Cybersecurity Landscape

The digital economy in Nigeria, including logistics, works in a larger cybersecurity environment that is marked by policies that are not always followed and are not always followed. The National Cybersecurity Policy and Strategy (2021)

shows that the government aims to make the country more resilient, but enforcement and technical support remain inconsistent across sectors (Ken Research, 2025). Critics of Nigeria's cybersecurity framework say that many businesses still rely on security measures based on compliance rather than on proactive, risk-based defence strategies (Guardian Technology). Empirical evaluations of cybersecurity preparedness within Nigerian government agencies have identified considerable deficiencies in infrastructure, policy execution, and skilled workforce, with merely a small fraction exhibiting high levels of readiness (Ayodele, 2025).

b. Sector-Specific Challenges for Logistics Firms

Even though logistics companies in Nigeria are using digital tracking, IoT, and automated systems to improve their supply chains, there isn't much evidence that they have strong cybersecurity systems in place to support CPSS adoption. Cyber threats to logistics are a serious problem if left unchecked (AtlasOne Cyber; BlueVoyant). They're like global trends in the maritime and supply chain industries, where ransomware and phishing attacks are on the rise. In Nigeria, logistics companies' ability to integrate CPS and CPSS is constrained by limited infrastructure, a shortage of skilled workers, and insufficient investment in cybersecurity solutions (Ken Research, 2025). So, even though logistics companies are making their processes more digital, they are still not very prepared for CPSS in cybersecurity. This is because their infrastructure is not up to par, which makes it hard to adopt and reduce risk.

III. SUMMARY & CONCLUSION

This study investigated the preparedness of Nigerian logistics companies to incorporate Cyber-Physical-Social Systems (CPSS), emphasising technological, human resource, organisational, and cybersecurity infrastructure. Utilising established theoretical frameworks, including the Technology Readiness Index (TRI), Diffusion of Innovation (DOI) theory, Human Capital Theory, and the Technology–Organization–Environment (TOE) framework, the study evaluated the preparedness of Nigerian logistics firms to implement advanced socio-technical systems that amalgamate digital intelligence, physical operations, and human interaction.

The results show that logistics companies in Nigeria are not well prepared for CPSS integration, and their readiness is inconsistent. More and more businesses are adopting basic digital technologies such as GPS tracking, logistics apps, and warehouse management systems. However, advanced CPSS features such as integrated IoT platforms, real-time cyber-physical control, and socially informed decision systems remain limited and are mostly found in a few tech-driven companies. The readiness of the workforce is limited by big gaps in digital skills, advanced ICT skills, and knowledge of cybersecurity, which shows that there are bigger problems with workforce development. Organisational readiness is also limited by leaders' lack of commitment to digital transformation, poor change management practices, and misalignment between technology investments and strategic goals. Additionally, cybersecurity infrastructure readiness is still not where it needs to be. Most businesses still rely on reactive security measures that put CPSS-enabled operations at greater risk of cyberattacks.

In conclusion, Nigerian logistics companies are making small steps towards digital transformation, but they are not yet fully ready for CPSS integration. To close this gap, we need to make coordinated investments in digital and cybersecurity infrastructure, continue training our workers, make our organisations more committed to innovation, and ensure that our rules and policies are helpful. If Nigerian logistics companies don't make these kinds of improvements across the board, they might not be able to fully leverage the operational and competitive benefits that Cyber-Physical-Social Systems offer in the evolving global logistics landscape.

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