JOURNAL OF LOGISTICS CONFERENCE TRINCOMALEE 2025

LEVERAGING ADAPTIVE LOGISTICS IN BUILDING RESILIENT SUPPLY CHAINS IN A VOLATILE GLOBAL ECONOMY

NAVAL & MARITIME ACADEMY

LOGISTICS CONFERENCE TRINCOMALEE - 2025

JOURNAL

"Leveraging Adaptive Logistics in
Building Resilient Supply Chains in a Volatile Global Economy"

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LOGISTICS CONFERENCE TRINCOMALEE - 2025: JOURNAL

The Journal of "Logistics Conference Trincomalee - 2025" is published as an integral part of the conference held on 31st May 2025 at the Naval & Maritime Academy (NMA), Trincomalee. This conference is jointly organized by the Logistics branch of Sri Lanka Navy and NMA and as the graduating activity of the Long Logistics Management Course (LLMC) conducted at the NMA. Student officers of LLMC No 09 have contributed to organize this year's conference with the exposure they have gained during the year long course.

This journal is a collection of papers contributed from the outside organizations, serving members of military services and the student officers of LLMC No 09. Journal will provide insight of the Logistics activities in the country, under the theme of ***Leveraging Adaptive Logistics in Building Resilient Supply Chains in a Volatile Global Economy***. This document focuses its attention on the logistics potentials and its competitive advantages for the development of Sri Lanka, which is uniquely position to leverage its opportunities to become a hub as one of the emerging economies in the region.

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MESSAGE FROM THE COMMANDER OF THE NAVY

It is an honour and a privilege to contribute this message to the Journal of the Logistics Conference - 2025, held under the timely and thought-provoking theme: "Leveraging Adaptive Logistics in Building Resilient Supply Chains in a Volatile Global Economy." This theme speaks not only to the challenges we face today but also to the opportunities that lie ahead, where logistics is recognized as a strategic enabler of resilience, operational readiness, and national prosperity.

In the maritime domain, logistics is far more than a support function, it is the silent force behind every naval operation. From fuelling ships and sustaining crews to facilitating rapid deployments and humanitarian missions, logistics transforms operational capability into strategic reach. For the Sri Lanka Navy, it forms the foundation upon which we project presence, protect vital sea lines of communication, and safeguard maritime interests across the Indian Ocean.

Yet the significance of naval logistics extends beyond defence. As an island nation heavily reliant on maritime trade, Sri Lanka's national security and economic stability are closely intertwined. Robust and adaptive logistics systems are essential to ensuring the uninterrupted flow of commerce, the protection of critical infrastructure, and a timely response to crises, whether driven by conflict, disaster, or disruption.

In today's unpredictable global environment, conventional approaches are no longer sufficient. The digital transformation of supply chains, proactive risk management, and the adoption of sustainable practices are no longer aspirations; they are imperatives. These adaptive strategies strengthen not only the Navy but also the broader national logistics ecosystem, enabling us to absorb shocks, maintain continuity, and emerge stronger.

I extend my sincere appreciation to the organisers of this conference for their dedication and foresight, and to the contributors and editorial team of this journal, whose efforts have created a valuable platform for knowledge sharing and professional dialogue. Let the proceedings serve as a testament to our shared commitment across services, sectors, and disciplines to advance logistics as a vital pillar of national strength. In doing so, we fortify not only fleets and supply chains but also the very foundation of our nation's future.

BAKSP Banagoda, RSP, USP, ndc, psc, MMaritimePol, MBA in HRM, PG Dip in HRM, BMS, Dip in Mgt, AFNI, JP (Whole Island)
Vice Admiral
Commander of the Navy

MESSAGE FROM THE KEYNOTE SPEAKER

Digitalization has been an integral component of the life of all global citizens. Businesses largely invest in digital transformation to equip their human potential with technological advancements to embrace competitive advantage. Industries across the world have been transforming their business models into digitalized value chains whereas human components are also upgraded accordingly. The soft economies operating in the global context are thriving with service value addition featured with digital platforms.

Sri Lanka is blessed by many a natural competitiveness against the rest in the global economic landscapes. As a service driven economy, Sri Lanka should focus on sustainable and competitive strategies to transform its service industries mainly tourism, logistic, education, ICT, facilities management and even education to embrace the global competitiveness. Alongside, the potential we have as a country for logistics should be seriously relooked and no sooner should it transform into global standards. Sri Lanka as a hub of the world trade roots found in the Asian context, has immense potential as a service supplying destination. The giant economies like China and India should be closely associated to obtain the holistic advantages for us to penetrate the logistic and supply chain business opportunities. The world's largest economies and their respective industries need quality logistics services. Thus, Sri Lanka should be seriously focused on the global supply chain roots and then develop the facilities and the country brand to penetrate those logistic business opportunities. The notion of digitalization is one of the key success factors for Sri Lanka to develop its value proposition to penetrate international logistic business opportunities.

The readiness of the institutes and professional organizations to facilitate the knowledge and infrastructures to digitally transform the logistic industry is a crucial factor. Professional institutes, academics, military service engage with logistic operations and the policy development entities should work together for a national plan to uplift logistic as a prominent industry. Thus, I believe creating forums to discuss and unveil the insights of different stakeholders found in the logistics industry is a strategic need to capitalize the potential of logistic industry. The country brand image for logistic should be established and positioned amongst global players to market Sri Lanka as a professional location for logistics services. In addition to academic & professional institutions, the manpower-driven sectors like military services could play a significant role to modernize the logistic services with their know-how. Thus, imparting the hands-on knowledge and professional thoughts of experts and researchers could provide the required inputs to improve the logistic industry in the country. The professional network building via this type of forums could generate a strong strategic network to discuss, research and strategize the overall logistic value chain model in Sri Lanka. Thus, whilst congratulating all stakeholders engaged with this timely valued conference, I would like extend an invitation to the respective communities to steer towards actions based on the insights delivered via this research forum.

Prof. (Dr). D.M.R.Dissanayake
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MESSAGE FROM THE DIRECTOR GENERAL LOGISTICS

It is my great pleasure to extend this felicitation message as the Director General Logistics of the Sri Lanka Navy for the Logistics Journal being published on the occasion of the 07th Edition of the "Logistics Conference Trincomalee", organized by the course participants of the 09th Long Logistics Management Course (LLMC).

The LLMC at the Naval and Maritime Academy (NMA) was initiated on 30th January 2014 to fulfill a long-standing need for higher professional training among logistics branch officers. The primary objective of this initiative is to enhance professional knowledge in Logistics Management, enabling logistics officers in the Sri Lanka Navy to perform duties professionally. With the training imparted at NMA, I am confident that they will face dynamic challenges with competence and the knowledge acquired through this course will empower them to find solutions proactively.

Further, I strongly believe that the Logistics Conference serves as a valuable platform for policymakers in both the military and corporate sectors, offering insights into best practices in logistics from both sectors. Furthermore, the theme of this year's conference "Leveraging Adaptive Logistics in Building Resilient Supply Chains in a Volatile Global Economy" is a highly relevant topic that demands research and discussion. As Sri Lanka works towards economic resilience following the pandemic and economic crisis, exploring this subject is critical to ensure sustainable development. I sincerely hope that this conference will make a meaningful contribution to theoretical, empirical and practical discussions in the field of logistics.

I would like to convey my sincere appreciation to the Commander of the Navy for his invaluable guidance, inspiration, and encouragement in making the "Logistics Conference Trincomalee - 2025" a resounding success. My sincere congratulations also go to the Commandant Naval and Maritime Academy, the Senior Course Coordinator LLMC, the Directing Staff, the Editorial Board and the course participants for their tireless efforts in organizing this prestigious event.

Finally, I extend my best wishes to all participants, speakers, invited delegates and I hope that the "Logistics Conference Trincomalee - 2025" will serve as an exceptional forum for knowledge dissemination and professional growth.

RR Kalubowila, USP, MBA (LM), LLMC, QPSO, CMILT, MISMM, MIM (SL)
Rear Admiral
Director General Logistics

MESSAGE FROM THE COMMANDANT NAVAL & MARITIME ACADEMY

I am honoured to pen this message as the Commandant of the Naval and Maritime Academy to the journal published on the occasion of the 'Logistics Conference 2025' themed 'Leveraging Adaptive Logistics in Building Resilient Supply Chains in a Volatile Global Economy.'

As the flagship conference of the Navy's logistics branch, this conference has grown over the years, empowering naval logisticians to critically analyze a range of facets in the field of logistics.

The articles featured in this edition encapsulate a wider spectrum of strategies and perspectives that address how organizations can harness flexible, data-driven logistics practices to enhance responsiveness, reduce risk, and ensure continuity in the face of geopolitical, environmental, and economic disruptions. Further, the journal has served as an important means that continues to encourage naval logisticians and subject matter experts from different entities to enhance critical thinking and present novel solutions to emerging challenges in the logistics field.

I would like to commend the authors and the editorial board for their commitment to advancing knowledge relevant to the theme of this edition of the journal. The journal has immensely contributed to the efforts towards leveraging adaptive logistics in building resilient supply chains.

Finally, I would also like to express my gratitude to the Commander of the Sri Lanka Navy, and Professor Ravi Dissanayake for accepting our invitation to share valuable insights as the keynote speaker. The unwavering assistance, guidance, and advice extended by the Director General Logistics along with his staff, and the dedication of NMA faculty are also mentioned here with a deep sense of appreciation.

R Joseph, RSP, USP, NWC, psc, MCPS, BSc (DS) Hons, Dip in D&WA
Rear Admiral
Commandant Naval & Maritime Academy

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SUB THEME 01

DIGITAL TRANSFORMATION IN SUPPLY CHAINS: LEVERAGING TECHNOLOGY FOR AGILITY AND EFFICIENCY

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ENHANCING INFORMATION TECHNOLOGY IN SLN FOR THE BETTERMENT OF THE SUPPLY CHAIN

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Abstract

This paper discusses the present IT infrastructure in the Sri Lanka Navy (SLN) and the challenges faced. The systems used are briefly elaborated with an emphasis on the Integrated Logistics Management System (ILMS). While discussing the drawbacks of the ILMS, adaptation of modern technologies to enhance the Information Technology (*IT) infrastructure and solutions for the ILMS which is a primitive ERP system is discussed. Overall, this paper discusses how to enhance the IT infrastructure for the betterment of the supply chain in SLN.*

Key Words: Integrated Logistics Management System , Information Technology

Introduction

With the evolving technology the world has evolved beyond imagination and continues to evolve. Certain operations that took couple of days, a decade ago takes only few minutes today. With the advent of Artificial Intelligence day to day activities of mankind has become easier as never before.

Similarly, the Logistics landscape has embraced technology and moving forward at a faster rate achieving improved efficiency. In this backdrop it is essential to transform SLN Supply Chain to be in par with the logistics practices in the world.

In order to move forward we need to study present landscape of SLN. Since the Logistics industry is increasingly becoming digitalized we need to understand the present capacities of Sri Lanka Navy in order to move forward.

Effective management of information technology (IT) in the Sri Lanka Navy is essential for ensuring the seamless execution of daily operations and maintaining operational readiness. It serves as a backbone for communication, decision-making, resource optimization, and security within the navy. Managing it effectively ensures that personnel, systems, and processes work in harmony to meet the demands of both routine and critical missions. Moreover, IT systems enhance decision-making by providing accurate data and analytics, allowing leaders to make informed choices based on current and predictive scenarios.

However, the reliance on it also comes with challenges: The out-dated systems, system downtime and inadequate system integration. Potential risks such as security threats, which can compromise sensitive naval operations needs to be addressed. Additionally, ensuring that personnel are adequately trained to operate IT systems requires on-going investment in education and skill development.

Despite these challenges, IT remains a vital tool for enhancing efficiency and resilience in the navy's daily operations. Balancing the benefits of advanced IT capabilities with proactive risk management and strategic planning is the key to leveraging its full potential in the Sri Lanka Navy.

Distribution of systems in navy can be categorised as follows:

a. Administrative systems.
b. Operational systems.
c. Public relations and community outreach systems.
d. Research and Development (R&D) systems.
e. Logistics Management systems.
f. Communication systems.
g. Health Management systems.

Commonly Used Systems in SLN

1. Human Resource Information System (HRIS)

This system is designed to streamline and manage critical human resource functions for Navy personnel. Key features include:

a. Service Records Management.
b. Recruitment Process.
c. Promotions & Appointments.
d. Personal Details.
e. Other Naval-Related Information.

2. E-Pay System

This system serves as a centralized platform developed specifically for the Pay Department to handle financial information for Navy personnel. The system includes the following:

a. **Pay Details Management**. The system allows individuals to view their current pay details, providing a comprehensive breakdown of salary components, including allowances, deductions, and net pay.

b. **Notices & Announcements**. The system publishes important notices and announcements from the Pay Department regarding payroll, allowances, and other financial updates, as well as updates from the Pension Department for retirees.

c. **Transparency & Accessibility**. The system streamlines access to pay-related information, reducing manual queries and enhancing transparency, allowing service members to easily view and understand their compensation details.

d. **Archival & Historical Records**. The system allows personnel to download past pay slips, providing easy access to archival and historical records for record-keeping or audit purposes.

3. Officers Leave Management System

This system is specifically designed to handle officers' leave applications electronically, streamlining the leave management process.

a. **Electronic Leave Applications**. The system allows officers to submit leave requests online, eliminating the need for physical paperwork, offering convenience, and significantly reducing processing delays.

b. **Authorization Workflow**. The system automates the transfer of leave requests to the relevant approving authorities, ensuring faster approvals or rejections while providing applicants with real-time status updates.

c. **Paperless Operation**. The system significantly reduces reliance on paper-based processes, leading to cost savings and contributing to environmental sustainability.

d. **Manpower Efficiency**. The system minimizes the workload of administrative personnel by automating the transfer and management of leave requests, freeing up resources to focus on other essential tasks.

e. **Record Maintenance**. The system ensures record maintenance by storing a digital archive of all leave applications and approvals, providing easy access for reference and efficient reporting.

Integrated Logistics Management System (ILMS)

Background and Development History:

1. **2006:** The system was outsourced to M/s Softlogic (Pvt) Ltd for initial development and implementation.

2. **2012:** The Directorate of ILMS was established to oversee and manage the system, with 05 Volunteer Naval Force (VNF) Officers enlisted as software developers to ensure in-house customization and improvement.

3. **2015:** The system was further strengthened with dedicated Logistics and IT staff to maintain, upgrade, and ensure its efficient operation. Main Modules of ILMS as follows:

a. **Stores Management Module**. The Stores Management Module tracks inventory levels and stock movement within the Navy, managing the demand, receipt, storage, and issue of materials. It provides real-time visibility into available stock across multiple storage locations, ensuring efficient management and distribution of resources. It includes following sub modules:

(1) SPDC/NSPDC Management Module.

(2) Victualing Management Module.

(3) Health Management Module.

(4) NAD Management Module.

b. **Procurement Management Module**. Procurement Management Module handles all internal procurement processes, facilitating requisitions, supplier selection, and purchase order issuance. It streamlines vendor management and ensures compliance with procurement policies, promoting efficient and transparent procurement practices. It includes following sub modules:

(1) Procurement management module

(2) Repair management module

c. **Budget & Finance Management Module**. The Budget & Finance Management Module tracks financial allocations and expenditures related to logistics operations, integrating budget planning with procurement and stores management. It provides detailed financial reporting, ensuring transparency in spending and supporting effective financial oversight. It includes following sub modules:

(1) NHQ Budget management module.

(2) Area Budget management module.

The ILMS serves as a centralized platform to digitize and streamline all logistics-related activities within the Navy. Its key purposes include:

a. **Seamless Demand and Issue Process**. The Seamless Demand and Issue Process ensure that all internal demands and material issues are processed through the system, promoting transparency and efficiency. Reducing paperwork and manual errors, enabling quicker and more accurate processing of requests is expected.

b. **Centralized Data Management**. Consolidating logistics, procurement, and financial data into one platform, to enable better decision-making through accurate reporting and analytics. This integration is expected to ensure seamless access to critical information for informed decision-making.

c. **Enhanced Accountability**. Ability to track all transactions to ensure transparency and accountability, preventing mismanagement and fraud is a key requirement of the system.

d. **Operational Efficiency**. Achieving operational efficiency through speeding up logistics processes and reducing reliance on manual operations is an important purpose of the system.

Challenges in Managing IT Systems in SLN

1. Outdated or Legacy Systems

SLN, depend significantly on outdated IT systems that fail to satisfy contemporary operational requirements. Such systems frequently lack the system capacity to accommodate emerging technology, resulting in inefficiencies and security vulnerabilities.

The age distribution of systems shows a significant portion in the 2–5-year range, which is approaching mid-life, and a smaller but significant portion is older than 8 years.

This distribution suggests the need for an active lifecycle management plan. Systems older than 8 years may face compatibility and performance challenges and could benefit from upgrades or replacement. Systems in the 5-8 year range should be evaluated for mid-life upgrades, while systems aged 0-2 years can serve as models for current technology standards and usability.

Non-licensed software in SLN increases cyber risks due to outdated security, lack of updates and minimum vendor support, making operations vulnerable to attacks and data breaches.

2. System Downtime and Maintenance Delays

Regular system outages caused by obsolete hardware, inadequate replacement parts, or poor technical proficiency might hinder naval operations.

3. Inadequate System Integration

The current systems used by the Navy are not very user-friendly, mainly due to out-dated technologies. Currently, the Navy utilizes several applications across diverse platform. Each system necessitates distinct URLs, usernames, and passwords, complicating the management of numerous logins for users. This may result in hesitance to utilize the system, who must access several programs (e.g., NAHA4, NAV 206, NAV 327, HRMS and the E-Rent System). The obligation of recalling several credentials might hinder users from completely engaging with these platforms.

Another example of multiple systems which are presently employed at the pay department to oversee different facets of the pay process. This contains eRent (utilised for inputting rent and ceiling information), eAllowance (used for processing allowances from various bases), and 327 (designed for aggregating all pertinent data for payroll processing). Currently, numerous recoveries (including non-public money, Seva Vanitha Unit, Wardroom, Welfare, etc.) and allowances are sourced from multiple sites, resulting in a complicated and fragmented procedure. Integrating all these systems into a unified system would be advantageous. An ERP solution may efficiently unify these disparate systems into a single integrated platform, streamlining the payment process and enhancing efficiency.

4. Integrated Logistics Management System (ILMS)

Even though the name suggests Integrated, ILMS is not integrated. There are three different modules with couple of sub modules under them which operate under different URL’s. Even the sub modules operate under different URL’s. As a result, an officer who needs to log in to all the modules will have to log in to each and every module separately.

The system is also not user friendly. Hence it requires training to all users. Further, the system is very slow especially in remote locations. Fleet units face numerous difficulties in logging in due to connectivity issues.

Further an officer who needs to order items from a different command, should first log into the command specific URL, observe the availability of the items, log out and log into the Command URL specific to his/her user location and raise a demand.

Facility for a user to change his/her location through the system is not available, hence required to signal NHQ. Also, there is no facility for a user to retrieve/ unlock his/ her password, through the system but needs to contact NHQ for the purpose.

Creation of item codes is done by a system operator at NHQ and hence, the risk of duplication of item code is existent. This system should be replaced with a bar code scanner which would enable creation of system generated item code which would be printed and pasted on the item enabling easy identification and issuing at the point of sales (POS).

Facility to generate Item codes through the system, by entering specifications for general items which may not have bar codes should be introduced.

Resistance to change from stake holders is the primary challenge. Interoperability, data security and system integration are the technical issues faced. Complexities of public procurement regulations complicate the implementation process. Moreover, SLN's Procurement module is already duplicated as the manual files are run concurrently.

5. Lack of Skilled Personnel

The information technology market is very competitive, and military organizations frequently have difficulties in attracting and retaining proficient personnel.

A deficiency of cyber security professionals may lead to protracted reactions to threats, rendering systems susceptible to breaches. Lack of technical proficiency can result in ineffective system management, extended downtime, and delayed integration of new technology.

Recommendations

1. Outdated or Legacy Systems

A phased approach to upgrading legacy systems is essential to ensure smooth transitions and uninterrupted operations. The Navy should prioritize high-impact areas for upgrades, adopt scalable platforms that can evolve with technological advancements, and secure funding for modernization initiatives. To keep pace with rapid technological advancements, the Navy should maintain and regularly update an IT strategic roadmap that aligns with broader defence objectives. Collaborating with technology providers and research institutions will ensure timely access to emerging technologies. Additionally, fostering a culture of continuous learning among IT personnel will enable the Navy to quickly adapt to new developments, ensuring the workforce remains well-equipped to manage and innovate within evolving technological landscapes.

To address cyber security risks from non-licensed systems, the navy should enforce licensing policies, provide cyber security training, centralize software procurement, conduct regular security assessments, strengthen cyber security frameworks, and invest in secure, licensed systems.

2. System Downtime and Maintenance Delays

Predictive maintenance, powered by AI and data analytics, can identify potential failures before they occur, significantly reducing system downtime. Comprehensive training programs for IT staff must be developed to equip them with the skills to handle maintenance challenges efficiently. Additionally, utilizing remote monitoring and maintenance tools can streamline operations and minimize delays, ensuring swift responses to issues. In parallel, investing in satellite communication systems and bandwidth optimization technologies is critical to improving connectivity. To ensure reliable communication channels, redundancy systems should be implemented to prevent disruptions in case of failures. Furthermore, partnerships with telecommunication providers can enhance the Navy's access to advanced communication technologies, ensuring robust and uninterrupted communication capabilities across all operations.

3. Inadequate System Integration

Standardizing IT platforms and adopting enterprise resource planning (ERP) tools can address system integration challenges, ensuring interoperability across the Navy's IT infrastructure. Regular audits and updates of existing systems will help maintain compatibility and operational efficiency.

4. ILMS

'Promise.lk', the e- procurement platform, introduced by the government has addressed most of the challenges discussed. Moreover, it is now a requisite by the government. Shifting to 'Promise.lk', the e- procurement platform should be the way forward in securing transparency in procurement.

Determining factor in the supply chain is the speed. Therefore, whilst acknowledging the efforts made by SLN to develop its own ERP solution, it is high time to look for a more simplified, user friendly, efficient and proven ERP solution in the market and customize it to suit SLN's checks and balances governed by the Financial Regulations. Investing on such a solution will bring long term benefits to the SLN.

5. Lack of Skilled Personnel

Collaborations with academic institutions can be established to develop tailored training programs specific to naval IT needs, while offering scholarships, professional certifications, and recognition for outstanding performance can further enhance recruitment efforts.

The recruitment and retention of skilled IT professionals remains a significant challenge for the Navy. To address this, the Navy should offer competitive wages, career growth opportunities, and specialized training programs to attract and retain talent.

However, due to defence services wage structure, offering competitive wages would not be a possibility. Out sourcing IT services may be the alternative. Thereby, SLN would be able to employ the best professionals in the industry. Therefore, feasibility of outsourcing IT services should be studied for greater benefit.

6. Modern Technology

Additionally, adoption of modern information technologies discussed below will revolutionize the operational capabilities of SLN. These technologies, ranging from artificial intelligence to block chain, enable navies to enhance efficiency, safety, and strategic decision-making.

a. Cloud Computing. Cloud computing facilitates secure data sharing, centralized fleet management, and advanced training simulations. As an example, The U.S. Navy employs cloud-based Enterprise Service Desk (NESD) solutions to streamline IT service delivery and provide efficient support to personnel and systems.

b. Artificial Intelligence (AI) and Machine Learning (ML). AI enables computers to computers to perform tasks that require human intelligence. AI would bring unparalleled precision and adaptability in logistics operations such as demand forecasting, route optimization and inventory management. ML will enable predictive maintenance, optimize resource allocation, reduce wastage and enhance overall efficiency.

c. Internet of Things (IoT). IoT connects naval assets, enabling real-time monitoring of fleet systems, personnel safety, and environmental conditions. Smart ships equipped with IoT devices optimize resource utilization and operational readiness. As an example, The Indian Navy’s IoT-enabled systems, provide secure real-time communication and enhance network-centric operations.

d. **Virtual Reality (VR) and Augmented Reality (AR)**. VR and AR are used for immersive training, maintenance support, and mission planning. These technologies reduce costs while improving readiness and safety. As an example, The Royal Navy uses AR for maintenance guidance and VR for simulation based training programs.

e. **5G and Advanced Networking**. The adoption of 5G enhances communication speeds, supports IoT integration, and enables real-time data streaming for advanced technologies like AR/VR. As an example, The Royal Navy leverages high-speed networks to conduct information warfare exercises and integrate electronic and cyber operations

Conclusion

It is high time SLN invest on the aforesaid technologies. Out sourcing IT services and obtaining the expertise in the industry may be the way forward.SLN should also invest in a more simplified user friendly, efficient integrated and proven ERP solution which can be accessed using a single credential and may be accessible from mobile devices in order to streamline its Supply Chain.

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I would like to acknowledge the contribution of the Student Officers of Syndicate 'A' of 28th Sub Lieutenant Technical (Logistics) Course for the research component of this paper.

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Synopsys on Effective Management of Information Technology in Sri Lanka Navy by syndicate 'A' of 28th Sub Lieutenant Technical (Logistics) Course.

HARNESSING ARTIFICIAL INTELLIGENCE FOR OPTIMIZING WAREHOUSE MANAGEMENT IN SRI LANKAN MILITARY CONSTRUCTION PROJECTS

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Abstract

The use of Artificial Intelligence (AI) in warehouse management has revolutionized logistics and supply chain operations globally. This study explores the potential of AI-based solutions in optimizing warehouse management in the construction projects of the Sri Lanka Military. By leveraging AI technologies such as predictive analytics, autonomous inventory management, and robotic process automation, military engineering projects can be rendered more efficient, cost-saving, and decision-making capable. The research employs a case study approach, analyzing current warehouse management problems in Sri Lankan military and evaluating the impact of AI interventions. Findings are that AI can significantly enhance warehouse performances, efficiency in productivity and inventory management, strengthening safety and demand. However, challenges such as financial barriers, data security concerns, technological adaptation, and ethics must be addressed for successful implementation. The study provides actionable implications for military decision- makers and logisticians, suggesting a strategic adoption of AI in military warehouse management to foster operational readiness and performance.

Keywords: Artificial Intelligence, warehouse management, Sri Lankan military, construction projects

Introduction

Construction Engineering in military play a crucial role in facilitating accommodations, offices, stores and infrastructures for the military personnel as well as the nation building requirements. According to SL Army, (2022) military engineering need to provide engineering services to military establishments, assist civil authorities to maintain essential services in emergency situations and undertake different government development projects. With the rapid development of Artificial Intelligence (AI) integrated technologies, construction engineering field become much more advanced and modernized to comply with the contemporary engineering demand. AI introduced as a Computer Science in the mid of 1950 and became a powerful computerized tool for many fields including engineering, that enables to solve complex difficult problems without human intelligence (Pham and Pham, 1999). According to Yao (2025), AI became as the central controller of engineering innovations while integrating with various engineering fields. Considering the context of construction engineering, embrace sustainability, resilience, adaptability, live ability and smartness are the factors which need to ensure for effective supply chain in engineering perspective (Rogers, 2018). In order to provide a resilience engineering services, effective application of warehouse management is utmost important in the military branches who undertake the responsibilities of construction logistics. According to the present paradigm shift of AI era, military too need to move forward with latest technologies to simulate with the global technologies. However, Sri Lankan military construction warehouse management is still not upgrade to this AI era due to lack of technological infrastructure and knowledge. Therefore, this article is to harness the AI for optimizing warehouse management in military construction projects. Accordingly, this article will be unfolded as Literature review, Methodology, Data analysis and discussion, and conclusion with recommendations. The objectives of the study are as follows:

1. To identify the existing AI potential in construction warehouse management which applicable to Sri Lankan military.

2. To examine the reliability of AI applications when using at the warehouse management of military engineering projects to optimize the resilience.

Literature Review

Military Supply Chain including the warehouse management is generally integrated with both military and civilian logistics providers, where necessary standardized performances required to maintain (Sokri, 2014). This is required to maintain effective cooperation to achieve the project outcomes handle by the military. The process of warehouse consist with receiving, put away, storage, picking, sortation, consolidation, value adding services, packing and dispatch (Richards, 2017).

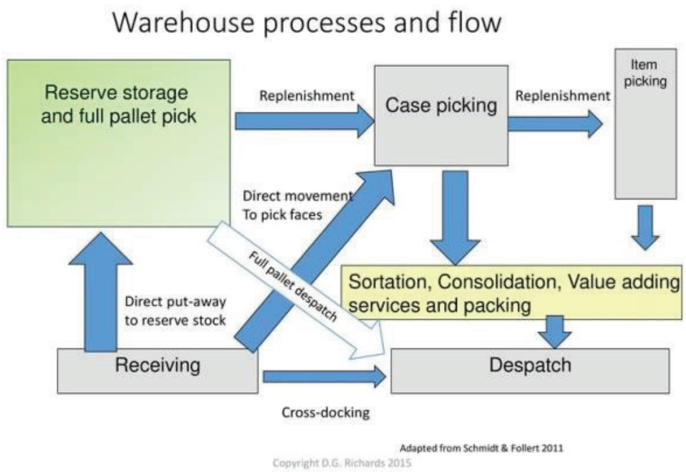

Figure 1: Warehouse Process and Flow
Source: (Richards, 2017)

Artificial Intelligence is one of the most prominent technologies in today which giving the capability to machines to communicate with and imitate the capabilities of human (Toorajipour et al., 2021).According to Gomes (2025), the common challenges that can be mitigated by using AI are project delays, cost overruns, safety hazards, and quality control problems.

The Evolution of Warehouse Management Automation

According to GreyOrange (2022), warehouse automation began from year 1901, from introducing of steel conveyor belts. In 1917, forklift truck introduced as a Material Handling Equipment (MHE) to the warehouses which made picking process effective. The first Automated Storage and Retrieval System (ASRS) invented in 1950 and enabled to pick and retrieve items while moving up and down storage racking. Adopting computer and IT solutions applied in to warehouse management since 1980 by introducing software-controlled technologies. From 2000, robotics introduced to warehouses such as Autonomous Mobile Robot (AMR) and Automated Guided Vehicle (AGV). Further, as per Byrne (2024), technologies such as barcode scanning and Radio Frequency Identification (RFID), allow operators to simply scan and pick the items with minimum time. At present, AI play a crucial role in warehouse automation by enabling optimize the warehouse, improve efficiency and reduce costs. Moreover, AI powered warehouse automation can reduce stockout, predict demand and adjust inventory levels by effective analyzing and optimizing the system.

AI Applications in Warehouse Management

The classical Artificial Neural Network (ANN) models and computer vision technology applications are used in modern warehouse management for object classification purposes (Yang and Rasul, 2021). As they emphasized, these systems enable use of face recognition, moving vehicle classification and counting, which are easy to recognize objects on the floor or the ground. According to Toorajipour et al. (2021), ANN can effectively utilize to find the complex patterns in warehouses where many stores available that human cannot find. It is demonstrated by the US Navy of smart warehouse with 5G capability integrated with AI in April 2022 (Demarest, 2022). It consists with AI driven automated robotics, predictive analytics for inventory management and enhanced decision-making capabilities with AI.

Figure 2: Smart Warehouse at US Naval Base Coronado in San Diego
Source: (Demarest, 2022)

The Ocado distribution warehouse in Lutan, United Kingdom reduced 1000 of people from the warehouse by introducing automated picking machine which integrated with the AI (Butler, 2025). Though they had to invest a considerable financial amount initially, this system created strategic advantages to the company by reducing labor cost and saving time.

Figure 3: Automated Picking Machines at the Ocado Distribution Warehouse
Source: (Butler, 2025)

Further, US Army Corps of Engineers (USACE), too applied the AI in their construction storages which optimize their military construction supply chains and warehouse management (USACE, 2025). The AI predictive analysis have used in their warehouses to predicts material requirements for the construction projects while ensuring those materials (sand, cement, steel, electrical items etc.) are readily available at the needed times. They use autonomous warehouse management using AGVs and AI powered robots, IoT integrated sensors to ascertain warehouse condition, digital twin models for warehouse management, and AI-driven exoskeletons assist soldiers in handling heavy materials to enhance the operational resilience in completion of their construction projects.

As Emig (2017) emphasized in his study the application of renewable energy resources, robotics, and artificial intelligence provides several benefits in military warehouses by considering US Marine Corps. It enables greater energy saving, reduce workforce requirement and fatigue, and effective inventory management capabilities. Further, it described that AI permits the user to speak commands and the system can understand it. The inputs such as location, specifications or any other attribute can use in AI integrated systems to process corresponding actions. Moreover, AI provide recommendations and insights for decision making in warehouse management while reducing the cost of human labor hours.

According to Singh and Adhikari (2023), AI can effectively use in demand forecasting, stock optimization, automated reordering, supplier selection and relationship management in both warehouse management and inventory management. These functions help any warehouse to achieve significant labor cost reduction, superior levels of productivity, a high degree of efficiency, minimal risk of processing errors, improved inventory management, increased supply chain speed while ensuring the safety and security of workers and the materials (Byrne, 2024). Further, there are several challenges which need to be considered during AI integration as emphasized by both Mishra and Silakari (2012) and Byrne (2024) at their studies as dependance of accuracy on data quality and integration, complexity of the models, integrating with existing systems, cost and resource constraints and ethical and privacy concerns.

Methodology

This study is conducted in interpretivism research philosophy by considering insights of the personnel who involve in engineering warehouses in military. The existing researches were tested as a deductive approach to the study while gathering data as a case study strategy to Sri Lankan military construction engineering fields. Data analysis was done as a mixed method choice and facilitation techniques by analyzing qualitative data quantitatively. The time horizon used for the study is cross sectional and data collected from both primary and secondary sources. According to the above literature review conceptual framework and operationalization for the conceptual framework are as follows:

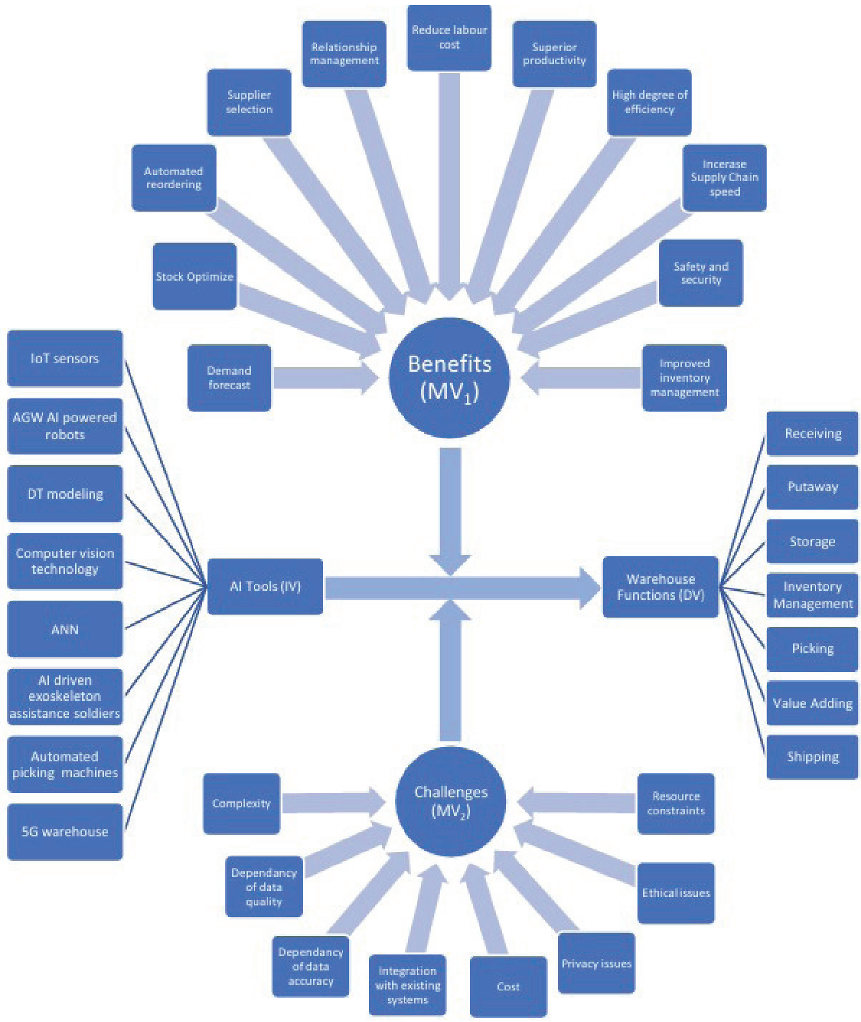

Figure 4: Conceptual Framework of the Study
Source: Literature Review

Ser	Variable	Indicator	Measurement	Source	Questions
(a)	(b)	(c)	(d)	(e)	(f)
1	AI Tools (IV)	Knowledge and experience about the following AI tools: a. IoT Sensors b. AGVs and AI powered robot c. DT modeling d. Computer vision technology e. ANN f. AI driven exoskeleton soldiers g. Automated picking machines h. 5G warehousing	Nominal	(USACE, 2025) (USACE, 2025) (USACE, 2025) (Yang and Rasul, 2021) (Yang and Rasul, 2021) (USACE, 2025) (Butler, 2025) (Demarest, 2022)	1.What are the AI tools you know which may use at warehouse management? 2. What are the AI tools you experienced at warehouse management?
2	Warehouse Functions (DV)	Receiving	Nominal, Likert Scale Likert Scale	(Richards, 2017)	1. What are the methods using in warehouse? a. Manual b. Automatic c. Semi-Automatic d. AI integrated 2. Do you believe that the present system is effective in warehouse management practice? 3. Do you think that AI can optimize the warehouse cost and efficiency than present practice?
		Put away	Do		Do
		Storage	Do		Do
		Inventory Management	Do		Do
		Picking	Do		Do
		Sortation, consolidation, Value adding and packing	Do		Do
		Dispatch	Do		Do

(a)	(b)	(c)	(d)	(e)	(f)
3	Benefits (MV_1)	Demand forecast	Likert Scale	(Singh and Adhikari, 2023)	1. Do you think that AI can enhance this factor in warehouse management than your present practice?
		Stock optimizes	Do		Do
		Automated reordering	Do		Do
		Supplier selection and relationship management	Do		Do
		Reduce labor cost	Do	(Byrne, 2024)	Do
		Superior productivity	Do		Do
		High degree of efficiency	Do		Do
		Increase supply chain speed	Do		Do
		Safety and security	Do		Do
		Improved inventory management	Do		Do
4	Challenges (MV_2)	Complexity	Likert Scale	(Mishra and Silakari, 2012) and (Byrne, 2024)	1. Do you think that integrating of AI is much challenging due to this factor than present practices?
		Dependency of data quality and accuracy	Do		Do
		Integration with existing systems	Do		Do
		Cost	Do		Do
		Privacy and ethical issues	Do		Do
		Resource constraints	Do		Do

Table 1: Operationalization of Conceptual Framework
Source: Developed by author

A google form questionnaire according to the above table 1, shared with officers of Sri Lanka Army, Navy and Air Force who involve in construction projects and related warehouse management. The questionnaire shared among officers as the snowball sampling techniques since the target population is undefined due to time limitation and access limitations. So that 14 officers from the Sri Lanka Army, 9 officers from the Sri Lanka Navy and 14 officers from the Sri Lanka Air Force participated for the questionnaire survey by sharing their insights. Since all the questions were prepared as compulsory to submit, there were no missing values in the data set. Further, all questions were designed as multiple choice answering and Likert scale questions, thereby no extreme values scored by the participants. The collected data, analysed through IBM SPSS Statistics software by descriptive statistics and exploratory factor analysis technique.

Data Analysis

According to the data analysis of demographic data, it is described that major involvement of constructions by the participants are on military infrastructure development works. Secondly, national development projects having considerable contribution and post disaster and humanitarian construction, commercial and civilian projects too undertake by them as figure 5 explicated.

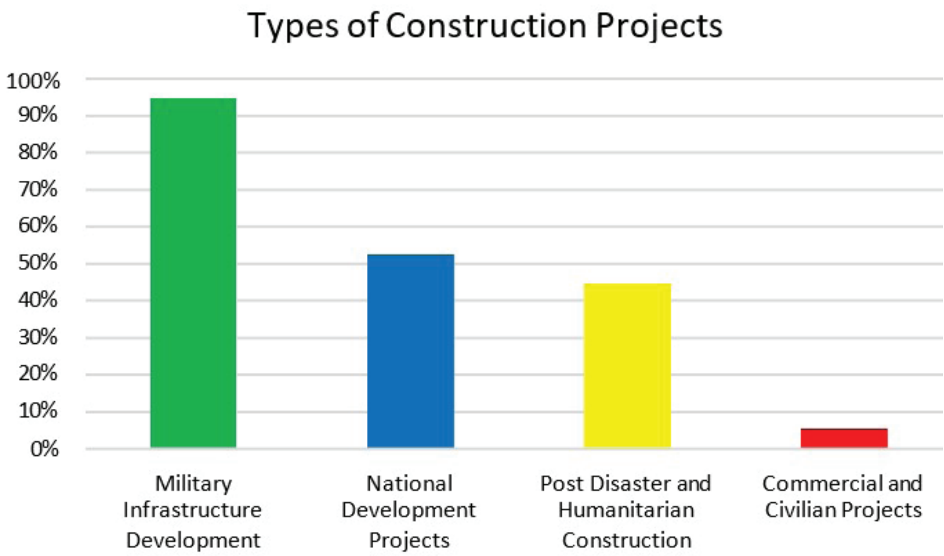

Figure 5: Types of Construction Projects Involve by Sri Lankan Military
Source: Questionnaire responses

When considering the knowledge and experience of the participants regarding the present AI integrated practices at warehouses in contemporary world, it is explained that 51% are not aware of any of the modern technology and 89% have not experienced those technologies in their present warehouse practices. As figure 6 depicted 35% of participants are aware on IoT sensor technology and very lesser number of participants know about the use of other AI technology for warehouse management. The reason for this lapse is that still Sri Lankan military practices primary level of manual warehouse management techniques (56.76%) and simple semi-automated machines (43.24%) as per the responses of participants depicted in figure 7.

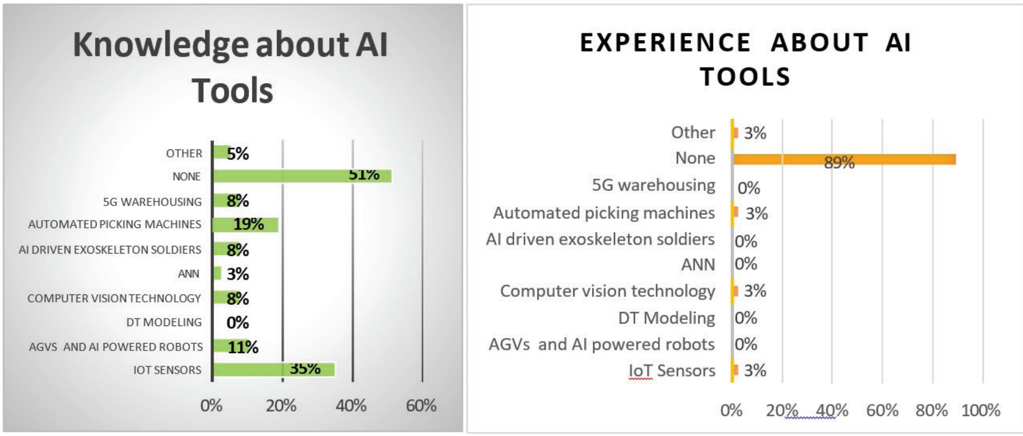

Figure 6: Knowledge and Experience of AI Technology among Research Participants

Source: Questionnaire responses

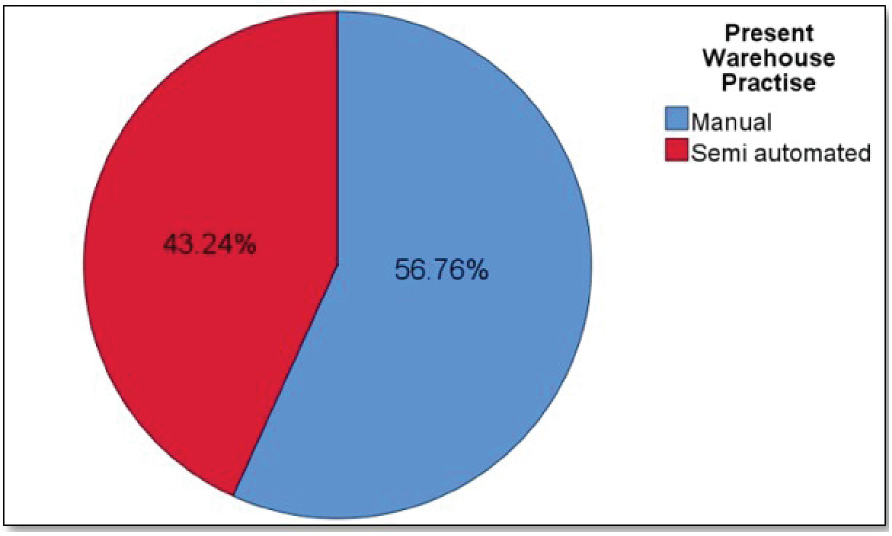

Figure 7: Present Warehouse Management Practices of Sri Lankan Military Construction Projects

Source: Questionnaire responses

However, as per figure 8 below, majority of participants (35.14%) believe that present warehouse management practice at their construction projects is not effective enough for efficient functioning of the projects. It can be imagined that 37.84% of participants remain neutral opinion about the effectivity of present practices due to their lack of knowledge of other systems as previously discussed.

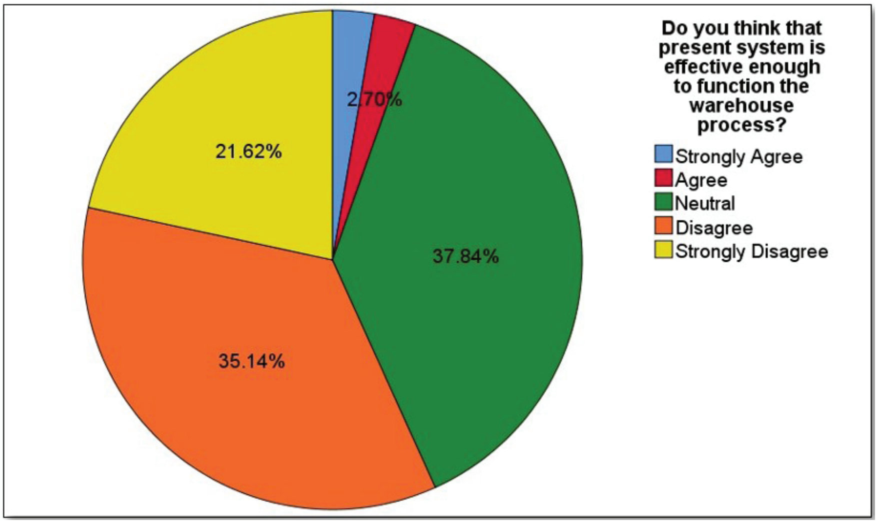

Figure 8: Participants Insights about Present Warehouse Management System
Source: Questionnaire responses

As per the data analysis related to benefits and challenges of AI in warehouse management, through IBM SPSS Statistics software by exploratory factor analysis technique and Principal Component Analysis (PCA) methods, the generated report is attached to this study as an Annex. According to the analysis report, six factors extracted based on eigenvalue (>1). The contribution of indicators for each factor explained by the rotated component matrix. According to the above mentioned matrix, contribution of high loading indicators is as follow:

Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Automated Reordering (.828)	Labour Cost Reduction (.835)	AI Complexity Challenge (.880)	Safety & Security Enhancement (.794)	Higher Initial Cost (.923)	Data Quality Dependency (.884)
High Degree of Efficiency (.814)	Inventory Management (.744)	Integration Difficulty with Existing Systems (.483)	Demand Forecasting (.643)	Resource Constraints (.678)	Privacy & Ethical Issues (.494)
Stock Optimizing (.714)	Superior Productivity (.594)	Privacy & Ethical Issues (.466)			
Supply Chain Speed (.604)	Supply Chain Speed (.444)				
Superior Productivity (.481)					
Supplier Selection & Relationship Management (.445)					

Table 2: Tabulation of Contribution of Indicators on Factors Extracted
Source: Developed by author

By considering the indicators contribution, factors were categorized by the researcher as performance enhancing, efficient productivity and inventory, system adoption challenges, safety and demand overview, financial challenges and data handling issues respectively. Moreover, data were analysed separately for each service as selection variable method. The results were quite similar to the overall analysis due to each services participants have similar kind of knowledge and perceptions about the use of AI in warehouse management in military construction projects.

Discussion

As per the data analysis of the study, military infrastructure development projects are the major involvement of Sri Lankan military and they further involve with National development projects and post disaster and humanitarian construction projects too. Additionally, there are commercial and civilian projects too undertake by Sri Lankan military to support for country's sustainment. Therefore, construction material warehouses are maintaining at each level according to the requirement of the project as per the Richards (2017). With having 95% of confidence level, the knowledge of Sri Lankan military construction field officers of 37% to 65% are not aware about the modern AI technologies use in warehouse management practices. However. It is proven that 22% to 48% are aware on IoT sensors, 8% to 30% are aware about automated picking machine systems and 2% to 20% are aware about AGVs and AI powered robots' usage in warehouses. The knowledge about the other AI technologies is comparatively low as per the descriptive statistics. When considering about the experience of AI usage at construction warehouses the descriptive statistics with 95% confidence level shows that 79% to 99% of military officers in the construction fields are not experiencing the AI technologies in their warehouses presently.

According to the participants responds about their present warehouse management practices, 41% to 73% of military warehouses are using manual practices in warehouses (CI = 95%). In addition, 27% to 59% of military warehouses are practicing semi-automated technologies in the warehouses. However, automated and AI integrated warehouses are not functioning in any Sri Lankan military construction field at present.

Considering about the participants insights about the present warehouse management practices it is believed by the 72.98% of Sri Lankan military officers that present warehouse management practices are not effective to meet the competitive demand (Disagree – 35.14%, Strongly Disagree – 37.84%). 21.62% of Sri Lankan military officers remains neutral perception about the effectiveness of present warehouse systems since they are not aware and experienced about the other systems. However, 5.40% of significantly lower amount of Sri Lankan military officers only believe that present warehouse management systems are effective (Strongly Agree – 2.7%, Agree – 2.7%). As per majority insights it can confirm that present warehouse management systems are extremely not effective in management of warehouses at construction fields.

According to the existing knowledge of Sri Lankan military officers who involve in construction warehouse management (table 2) interpretation of insights are as follows:

1. **Performance Enhancing**. Singh and Adhikari (2023) and Byrne (2024) introduced several benefits of using AI in warehouse management systems. As per the data analysis of this study it is proved automated reordering, high degree of efficiency, stock optimization, enhanced supply chain speed, superior productivity and effective supplier selection and relationship management are the major contributors for the performance enhancing of warehouse functions when integrating of AI at the warehouse functions.

2. **Efficient Productivity and Inventory**. Out of the benefits explained at Singh and Adhikari (2023) and Byrne (2024) , labor cost reduction, efficient inventory management, superior productivity and enhanced supply chain speed are the indicators that cause for efficient productivity and inventory. According to the military construction warehouse perspective, those factors show high loading indication for the efficient productivity and inventory in warehouse management.

3. **Safety and Demand Overview**. It is confirmed by the analysis that safety and security enhancement of men and material (Singh and Adhikari, 2023) in the warehouses can be ensure by the AI integration. Further, demand forecasting can be accelerate (Byrne, 2024) by using AI as participants stated.

4. **System Adoption Challenges**. As per the challenges of using AI at warehouse managements explained by Mishra and Silakari (2012) and Byrne (2024) and according to the above data analysis, challenges pertaining to the difficulties of integrating AI systems are complexity, difficulties in integration in to present ordinary warehouse management systems and privacy and ethical issues for users.

5. **Financial Challenges**. As per the existing literatures (Mishra and Silakari, 2012) and (Byrne, 2024), financial challenges due to high initial cost and resource constraints are the major drawbacks of integrating AI into the warehouses. As per the Sri Lankan military perspective, high initial cost and resource constraints are such significant factors which affect integration of AI into military construction warehouses due to country's present financial status.

6. **Data Handling Issues**. As (Mishra and Silakari, 2012) and (Byrne, 2024) emphasize at there studies data handling issues in respect of data quality dependency and privacy and ethical issues are the another drawbacks of the AI integration and those indicators have been confirmed by the research participants too. However, comparatively lesser amount believes that privacy and ethical issues are critical in data handling in military context. Since the construction materials are not related to security concerns, it can be justified that privacy and ethical issues are not that much of a critical data handling issue in integrating AI into military construction warehouse.

Conlusion

Sri Lankan military being the key configuration of ensuring the National Security, extends its capacities in logistics aspects to sustain to maintain the fighting power. In the military logistics concerns engineering plays a pivotal role by engage with military infrastructure development projects, national development projects, post disaster and humanitarian projects and several commercial and civilian projects. Since the AI being the evolving tool in modern technological revolution, it has covered almost every fields even in logistics. This study was to test the feasibility of integrating AI into warehouses of military construction projects by interpretivism research philosophy through getting the insights of Sri Lankan military officers who involve in the military construction warehouses.

As per the study findings, it is noticeable that majority of officers in Sri Lankan military who involve with construction warehouses are not aware and experienced about the AI tools which can integrate to the warehouse management process. With the overall existing knowledge of them about the AI, it is recognized that majority are believing that AI can be effectively enhanced for the warehouse management systems through enhancing warehouse performances, efficient productivity and inventory management, strengthening safety and demand. However, it is identified that there are significant challenges to apply AI in to Sri Lankan military warehouses due to difficulties to adopt for existing systems, financial challenges and data handling issues.

Considering the benefits of using AI at warehouse management systems Sri Lankan military construction projects, it can achieve greater financial and material benefits with optimizing human resources which are significantly limited in the country's present status. Even though the initial financial investment is considerably high in AI integration, it will be a long term forecasted profit which enable to survive with minimum resources in future. Till the initiation of the AI in to existing warehouse management system, it will be a difficulty of integrating. Once the system is initiated through provision of adequate knowledge for the respective parties, this system will be such friendly and easy to handle as other AI tools available in the world. Data handling issues can be easily rectified in military due to the well-established disciplinary regulations can be upgraded to comply with the modern technologies. Further, Sri Lankan military being the professional workforce in the country it consists with many numbers of officers who are capable and qualified enough with the AI related higher studies. Without hiring professionals from the outside, Sri Lankan Military may initiate such project to integrate AI into military construction warehouse management systems.

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TRANSFORMING SUPPLY CHAINS: LEVERAGING TECHNOLOGY FOR AGILITY AND RESILIENCE

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Abstract

In today's volatile global environment, traditional supply chains and other systems are increasingly inadequate due to various disruptions such as technological advancements, pandemics, geopolitical barriers, climate changes, and consumer behavior changes. This study emphasizes the transformation of global supply chains by integrating with advanced technologies can uplift organizations in different aspects by enhancing resilience and agility. Key technological platforms currently used such as Artificial Intelligence (AI), Internet of Things (IoT) and blockchain can enhance the capacity to make predictive analysis, and real-time decision-making, improve operational efficiency, and improve the overall performance of organizations. By elaborating the real examples such as Maersk's IoT-powered container tracking systems illustrate the practical applications of the technology to transform the supply chains into better levels. Moving from linear supply chains to robust ecosystems can enhance organizational performance by fostering innovations, responsiveness, and flexible movements. The study further identifies and addresses the barriers to adopting to digitalized world in supply chain processes are mainly the legacy infrastructure, workforce fears, cyber security threats, and costs. The paper covers the strategic playbook for 2030 emphasizing sustainable practices, collaborative partnerships, and digitalization to build up a future-ready supply chain. In conclusion, embracing technological transformation is not only an option but also it is a forward step for organizations aiming to thrive in complex and volatile markets to make competitive advantage movements.

Keywords: Supply chain resilience, digital transformation, adaptive logistics

Introduction

The global economy has consisted of unprecedented characteristics that affect the global supply chain volatility such as geopolitical changes such as the trade war between the USA and China, unforeseen events, climate changes, technological disruptions, and shifting consumer demands. In these turbulent situations maintaining a resilient supply chain is a must for organizational survival and to have sustained growth in the market (Sathvika Reddy and Ashritha, 2024). The COVID-19 pandemic highlighted the cons of some models like Just in Time, that organizations used as production models. As figure 1 depicts, most of the manufacturers worldwide depend on China to get the raw materials for their production and they experienced severe production and supply chain disruptions during the global pandemic time as well (Richter, 2024). On the other end, because of China's digitalization in every industry, they gained a considerable level of competitive advantage over other countries. At the peak time of the crisis, 94% of the companies experienced supply chain bottlenecks, and automobile major companies like Toyota halted their production due to the supply chain disruptions (Ivanov, 2024). In response, organizations tend to move to adaptive logistics systems which can combine technological agility with supply chain strategies to enhance efficiency and resilience throughout the supply chain procedures. International Monetary Fund (IMF) implied that due to the Ukraine-Russia war global trade volatility has increased which creates barriers to international trade procedures (Elliott, 2024).

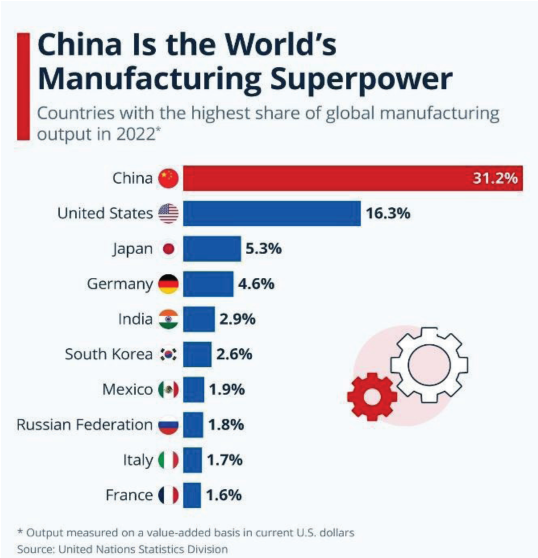

Figure 1: Global Manufacturing output
Source: (Richter, 2024)

Considering these situations logistics cannot rely on traditional methods and strategies instead they have to move to the adaptive logistics frameworks which integrate agile sourcing, digital transformation, and the collaborative ecosystem which can enhance the operational excellence in the global supply chains. Digital transformation can act as the milestone of the adaptive supply chains which support achieving the objectives of responding to disruptions on a real real-time basis, maintaining end-to-end operational efficiency, and achieving resilience through data-driven collaborations. As figure 2 shows, AI usage in the global logistics market has increased year by year due to the benefits that organizations can gain from that.

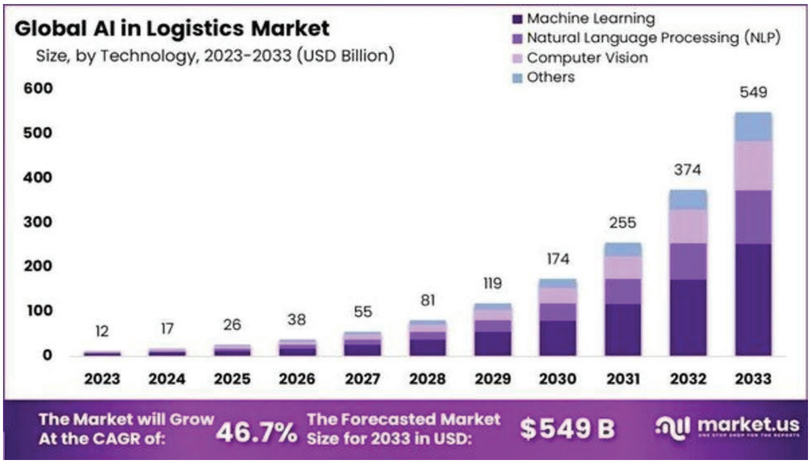

Figure 2: AI Technology in the Global Logistics Market
Source: (DC Velocity, 2024)

Adaptive logistics is not a concept which solely emerging it fundamentally involves shifting from reactive supply chain management to a proactive and predictive approach. Hence it enables firms to make real-time decisions makings which can reduce the risks of the operations. In essence, transforming the strategic supply chains from cost cost-centric approach to a strategic asset approach needs to be concerned with driving it as a competitive advantage.

Building Adaptive Logistics Through the Technological Pillars

1. Artificial Intelligence

The brain of modern supply chains can be identified as Artificial Intelligence (AI) and it has become the cornerstone of adaptive logistics which supports real-time decision-making in complex supply chain networks. AI and machine learning can analyze vast amounts of data sets and can identify patterns, optimize the routes, predict the demand amounts, and automate decision-making. It consists of various AI techniques such as machine learning, big data analysis computer vision, and natural language processing. This support system can give solutions for the volatile global economy which is rapidly changing and providing accurate responses to the disruptions is an essential part. As an example, AI can forecast demand changes based on historical data sets, real-time data, and based on market trends allowing organizations to maintain inventory levels and make decisions about the production schedules proactively. Google supply chain twin allows organizations to reduce disruptions like tariff changes and enables proactive actions for inventory adjustments (Lundström, Jansson, and Andersson, 2023). This ensures accurate and efficient decision-making in the areas of inventory planning and predictive analytics which enables to have proactive decision-making. Apart from that there are AI-powered route optimization systems that are used to dynamically adjust the delivery routes based on real-time traffic, supply chain bottlenecks as well as based weather conditions. Compared to Sri Lanka most of the other countries are using AI technology in supply chain processes. As Wu (2024) mentioned in 2024, Taiwan faced a tsunami situation and Taiwan Semiconductor Manufacturing Company's (TSMC) AI system rerouted 60% of the routes and within a few hours made the alternative air corridors which minimized the delays for clients.

2. Internet of Things (IoT)

This method can provide visibility into the operations of the supply chain procedures. IoT can enhance the visibility and tracking of goods throughout the supply chain process while reducing delays and optimizing inventory management (Lundström, Jansson, and Andersson, 2023). Currently, organizations tend to use smart sensors and monitor conditions to respond properly to disruptions. IoT applications have ranged from predictive maintenance on equipment to the stage of observing real-time condition monitoring of products in the process. Maersk shipping line's remote container management system uses IOT sensors to track the shipping containers while reducing the waste of perishable goods by maintaining the required temperature level. FedEx's upcoming regional factory in Dubai South's Logistics district will have, high-security screening equipment and an automated sorting system with capabilities to handle dangerous goods (Hinedi, 2023).

3. Blockchain

This is identified as trust infrastructure hence it adds value to transparency and enhances trust in the supply chains. This provides the platform to connect suppliers and manufacturers as well as retailers to share data among them. In logistics operations, IoT devices can check factors like temperature, speed, and humidity. Various industries have used blockchain successfully in their supply chain processes such as agriculture, pharmaceuticals, and specially the automotive industry. As an example, Walmart company uses blockchain to track the leafy greens in their farms and reduce the illnesses that can spread through the food products. Pfizer company uses blockchain for their drug traceability in their global distribution network. Beyond these benefits, blockchain can streamline operations and reduce bottlenecks while minimizing errors in the supply chain networks. Therefore, blockchain is not only applied to enhance operational efficiency apart from that it aligns to improve ethical as well as regulatory reasons (Lundström, Jansson, and Andersson, 2023). Blockchain has addressed most of the pain points in the logistics process as inefficiencies, vulnerability to disruptions, and lack of transparency. Through having smart contracts and enhancing traceability companies can promote sustainability and build resilience by reducing disruptions hence the blockchain represents a technological upgrade from certain perspectives (Sathvika Reddy and Ashritha, 2024). Maintaining this operational agility enables organizations to handle supply chain shortages effectively and maintain growth.

Operational Agility Through the Strategic Transformation

Strategic transformation for operational agility supports the restricting in an organizational operation to enhance the adaptability for the dynamic market and the changing customer demands with the technological advancements. This operational agility highlighted the importance of aligning the resources and the technologies with the strategic goals that the organizations trying to achieve. It ensures the organizational responsiveness to both long-term and short-term challenges and also for the opportunities. This is not only about enhancing efficiency it is about moving to innovations, collaborations, and improving the flexibility in the organization. As an initial step, it requires a rigid and linear workflow when adapting to the dynamic supply chain systems which can quickly respond to the external changes. As an example, Tesla highlighted leveraging vertical integration and real-time supply chain planning to decide the supply chain shortages and maintain growth in their production. As a result, businesses which are combining with the advanced technologies like data analytics, automation, and also AI can make faster and more efficient production by reducing inefficiencies while enhancing productivity.

1. From maintaining chains to building collaborative ecosystems

Supply chains need to improve as an efficient ecosystem rather than using a linear sequence. In the ecosystems concept suppliers, tech transfers, and customers create value for the logistics and supply chains through the share platforms. Ford Eclectic Vehicles (EV) built an ecosystem by collaborating with SK innovations (batteries), the Google Cloud platform (AI Analytics), and Redwood Materials (recycling) to make an end-to-end network that enhances efficiency compared to the traditional market. This approach supports mitigating the risk and it can accelerate the innovations since it has a pool of resources that cover each function of the supply chain process with having the expertise in every stage.

2. Balance the cost and the resilience

Apple company has a stagey named "China Plus One" which diversifies the production in India as well as in Vietnam reducing the reliance on the Chinese factories. Hence the geopolitical tensions and the trade wars in the world have influenced the companies to adopt the hybrid souring strategies to mitigate the risk and enhance the organizational capabilities. These steps can support the local manufacturing companies by giving them subsidies for the production process. Adidas has a concept as 'Speed factory network' which uses 3D printing and robotic technology to manufacture their products in Germany which can avoid the shipping costs by 30% and it support responding to the rapidly changing regional fashion trends (Young, 2017). These distributing micro factories enhance agility by decentralizing their production which addresses the customer requirements more efficient manner.

3. Green efficiency paradox

Moving to the circular supply chains by enabling the use of AI and IoT can minimize waste while maximizing the wastage which promotes the efficient use of resources. Therefore, sustainability and efficiency no longer need to be the conflicted goals. Patagonia has an AI-driven production platform that can sell about 200,000 used garments monthly which double their profit margin as compared to the new products. Initiating green logistics can reduce costs by moving toward eco-friendly products. Amazon uses electric delivery vans which produce with Rivian eliminating the 5 million metric tons of CO2 in 2024 which reduces their fuel expenses (Amazon, 2023). Even though companies have to bear a considerable amount of cost at the initial stage of sustainability transformations during the processes companies can gain remarkable benefits from that.

Overcome Challenges

The journey to adaptive logistics while gaining significant benefits to the company must address the implementation strategies proactively. These obstacles which span the technological, organizational, and human concerns require a holistic approach that can ensure the successful adoption of supply chains with long-term sustainability. Effectively overcoming these challenges is a crucial stage that needs to identify the organization's full potential in moving to digital transformation and achieving operational agility.

1. Legacy system barriers

The main hurdle that needs to go through is the integration of the legacy systems. Most organizations are reluctant to move to the modern technologies and still rely on the outdated infrastructure. This highlighted the significant number of investments in cloud-based platforms and AI-driven technologies which reduce the technological gap between the new and old systems that companies are using. Accenture study in 2024 stated that 68% of the manufacturers still rely on the ERP systems which they are more familiar with. Those systems are not using any AI or IoT technologies to enhance their efficacy. Azure's Supply Chain Hub introduces a solution that integrates with new tools and techniques without harming the legacy that they are maintaining.

2. Workforce 5.0

The World Economic Forum stated that 50% of the logistics workers need to have an upskilling by 2026 to work with a more technology-driven environment in which they have to work with AI and automation. UPS has a program to train their workers through VR training centers where drivers can master route optimization and also in drone delivery management. Bridging the skills gap is a must to upskill and reskill employees by making them capable of managing their work in this digitalized era. This also covers providing opportunities for employees to have continuous learning, certifications, and full of experiences.

3. Being protective in the digitalise era

Hence most of the functions are being digitalised the emerging threat for that is cyber threats. That is one of the reasons why organizations do not like to move to digitalized platforms. Cybersecurity ventures stated that including the ransomware targeting $92 billion amount losses from the supply chain attacks in 2024. Protecting sensitive data and infrastructure from cyberattacks requires a proactive approach which can be addressed by robust security protocols and threat monitoring systems. While maintaining the security in their organization they have to adhere that their stakeholders also are in the same high standards.

Playbook for 2030

Firms need to adopt a few strategies to adapt to the logistics trends. Organizations need to digitalize the core operations based on AI, IoT, and blockchain to gain efficacy in the supply chain processes. And also need to focus reinventing on partnerships by building agile ecosystems that have the proper system to support while getting the best support from industry experts. Can embed sustainability into each process that firms are following which supports to gain lots of benefits in different perspectives. As an example, the Maersk shipping line invested $1.4 billion in wind-powered cargo ships which can reduce fuel costs by 40% and support environmentally as well as economically.

By 2030, this adaptive logistics will make a huge impact in the industry and it will become the competitive advantage of companies which makes a firm highlighted among other competitors based on their baseline survival. Companies that are reluctant to digitally transform their business processes will face a huge impact which is a risk of 40% from the Fortune 500 companies are projected to collapse by 2030. Emerging technologies like generative AI will further revolutionize the industry by managing custom compliances and designing self-solving supply chains.

Conclusion

Digital transformation has fundamentally changed supply chain management, with emerging characteristics of increasing efficiency, flexibility, and transparency and focusing on satisfying customer needs. This insightful transformation has critically affected the operations in the supply chain process having extensive impacts. This will lead to enhancing resilience and maintaining sustainability by focusing on the three pillars of sustainability such as, environmental, social, and economic. Businesses are now moving to handle disruptions and adapt to changing market conditions which is essential for today's fast-paced market. Integration with digital technologies has led to significant positive factors in gaining productivity as well. Automation and advanced analytics have supported companies to make quick decisions that can enhance the overall firm's efficiency. One of the main drawbacks that companies have to face when highly dependent on the labor force is human errors. The use of automation comes at this point where the use of Robotic Process Automation (RPA) has minimized the human errors and inefficiencies of manual tasks. This shift is not only addressing the human error issues but also considering the costs, making the supply chain more agile with better responsiveness.

Companies can build a global network consisting of partners, suppliers, and customers more effectively which is an essential factor for competing in the global market. Every firm's main objective is to focus on customer centricity (Sathvika Reddy and Ashritha, 2024). The changes made by the digital transformation can impact customers and it elevated the importance of having customer-centricity in supply chains. Businesses are now properly positioning themselves to meet the customer demand and their expectations. As a result, digital transformation in the supply chain fosters the building of a culture of continuous improvement within organizations. This highlighted the ongoing changes in the business world that can build a competitive edge to achieve the firms' ultimate objectives.

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HOW BEST SRI LANKA NAVY CAPITALISE ON THE APPLICATIONS OF THE INTERNET OF MILITARY THINGS (IOMT)

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Abstract

Today most world militaries use the Internet of Military Things (IoMT) in various aspects to enhance accuracy, effectiveness and efficiency. Development of smart applications, sharing of data and maintaining of the data repository is significant in IoMT. However, IoMT is more vulnerable to cyberattacks and a sound cybersecurity system is required when using IoMT. Implementation of IoMT reduces the physical interaction of naval persons in various tasks related to logistic supply while enhancing accuracy and efficiency. The problem of the research derives from the fact that the SLN is in the process of right-sizing its manpower. Also, the SLN uses IoT in various disciplines. However, the application of IoMT logistic management is still in basic status when compared with other regional navies even though SLN has the capacity to some extent implement the IoMT for better logistic management. This research aims to close the significant research gap by exploring viable opportunities available in various disciplines within SLN to implement the IoMT effectively for better logistic management. This study uses a qualitative research methodology with a deductive approach. The study has found that SLN has capability in the application of IoMT for better logistic management under fleet monitoring, warehouse management and through networking or smart applications to avoid duplication of resources, efficient utilization and effective management of resources.

Keywords: Internet of Things (IoT), Internet of Military Things (IoMT), effective and efficient logistics management

Introduction

In particular, the Internet of Things (IoT) in the defence industry is also known as the Internet of military Things (IoMT) or Internet of Battlefield Things (IoBT). Moreover, Suri et al., (2016) explained that IoT are more vulnerable to cybersecurity attacks including risk of compromise or loss of data from the device, risk of false data, spoofing from the device, risk to the physical device and risk to the networks to which the device is connected. Johnsen et al., (2018) explained that the tendency to invest in IoT and Big Data Analytics (BDA) appears to be natural by technical innovation supply or demand. Also, the utilization of IoMT is much more effective for Human resources management (HRM) and Logistics management. Moreover, the presence of Wi-Fi, Z-Wave, ZigBee, and other wireless technologies act as Internet gateways.

Likewise, the presence of a Personal Area Network (PAN) such as Bluetooth device can communicate with a mobile phone via the PAN, which subsequently enables dependable internet access via cellular networks (Joseph, 2017). Importantly, Poulter and Mackay (2018) explained that IoMT technologies which are involved in warehouse management are mobile scanning devices, digital barcode and Radio Frequency Identification (RFIDs), IoT sensors, navigation systems and wireless Telemetry. Furthermore, the advanced equipment used are Robotics, GTPs (Goods to Person systems), Automated Storage and Retrieval systems (AS/RS), Automated guided vehicles/ Autonomous mobile robots (AGV/AMRs), sortation equipment and smart shelving & pallets. Below figure 1 illustrates how IoMT effective utilization for the store management.

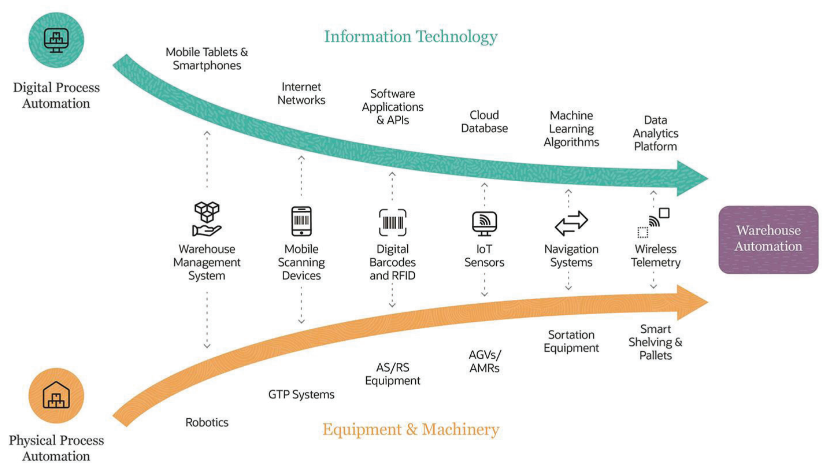

Figure 1: IoMT Applications in Warehouse Automation
Source: www.spiedigitallibrary.org

On the other hand, the Sri Lanka Navy (SLN) is in the process of rightsizing the force structure. Also, Kapugama, K. (n.d.) explained that the SLN must take extreme precautions to ensure that their capabilities are not jeopardised by cyber vulnerabilities given their increasing dependence on computer networks and systems while rightsizing the force structure. However, it is understood that the application of IoMT is very vulnerable while rightsizing the SLN to reduce human interactions where applicable in effective and efficient logistic management connecting all naval areas. Further, it is understood that the application of IoMT within the SLN will be much more effective when applied to fleet maintenance, fleet monitoring and logistics management by utilizing the available resources.

More specifically, it has been identified that SLN attempts to enhance the applications of IoT to reduce paperwork, utilisation of manpower and adopt effective logistic management. In particular, collective and effective utilisation of existing IoT within the SLN shall enhance the application of IoMT while providing various opportunities under several disciplines of logistic management. As explained in the SLN

BR 1, a solid logistics plan is essential for both planning and fighting any battle. More importantly, healthcare, repair facilities, staff mobility, the transportation of gasoline, lubricants, equipment, spare parts, food, and other supplies, as well as the numerous stores needed for operations, are all examples of logistical assistance (SLN BR 1).

The problem of the research derives from the fact that SLN is in the process of rightsizing the manpower. However, sound logistic management in SLN needs to continue to strengthen national security. On the other hand, SLN can operate IoT to its fullest ability with available resources for better logistic management. Even though SLN has the capacity to some extent to implement the IoMT in the field of logistic management with advanced options, SLN is lacking in implementation of advanced IoMT options.

This research aims to close the significant research gap by exploring viable opportunities available in the discipline of SLN logistic management to implement the IoMT effectively to enhance the conducting of effective and efficient functions of SLN logistic operations. Finally, the study provides recommendations for further implementation of IoMT in SLN for logistic management.

Methodology

This study uses a qualitative research methodology. Also, the study used primary and secondary data, which combined the primary data collection and desk reviews. Moreover, utilizing current knowledge and interacting directly with responsible naval persons, primary data collection allowed for a thorough investigation of the study problem. Moreover, the key informants were derived using the purposive sampling method, where they are the experts in the field. The rationale behind utilizing primary data through semi-structured interviews with the naval persons is they are the most vulnerable to the utilization of IoMT in the field of logistic management. In addition to primary data collection through interviews, the researcher also shared open-ended questions via Google form for various naval areas. A triangulation strategy was used to improve the finding's validity and reliability. The study can guarantee that the results are solid and consistent by integrating information gathered through desk reviews accessing numerous research papers, publications, relevant websites, open-ended questions, and interviews. This technique lessens prejudice and raises the research's general credibility. The ethical aspects and anonymity of the study process are carefully taken into account while presenting sensitive data. This entails getting each participant's informed consent, protecting the privacy and confidentiality of sensitive data, and abiding by the ethical standards set forth for studies involving human people.

Results and Discussion

It is important to highlight that SLN is in the process of rightsizing manpower while evaluating and analysing her role and task. Moreover, the primary and secondary roles of SLN are required to be highly considered while modernising SLN. On the other hand, SLN is required to consider the implementation of new technology while reducing human interactions where necessary. Further, at present world militaries are widely using the latest technology in numerous disciplines to better manage military things. Moreover, it was explored that the SLN also gradually adopted advanced technologies in various disciplines. More specifically enhancement of IoMT in the SLN shall provide better results in logistic management. However, due to financial constraints, SLN is facing challenges in acquiring more advanced, sophisticated and smart technologies.

Also, the study has found that numerous challenges also exist within the SLN context including the required resources as well when implementing the IoMT. Importantly literature has revealed extensively regarding the use of IoMT in logistics management. Moreover, it has been identified that SLA, SLN and SLAF have already developed a few mobile applications for some military requirements such as an e-pay system, obtaining GPS coordinates, Military abbreviations, internal general military message passing etc.

Furthermore, a study has examined that, there are resource persons within the SLN and civilian sector who can be utilised to develop various applications to enhance SLN logistic management utilising IoMT. It was identified that the use of the IoMT, including sensors and RFID, is fundamental for improving logistics operations. Moreover, this includes interoperability with third-party logistics systems, since many of the supplies required during naval operations consist not only of military equipment but also of subsistence and medical materials for the navy. On the other hand, SLN is functioning warehouse Island-wide in all naval commands for various purposes including storing spare parts and maintenance equipment. Moreover, it was examined that rations including the fresh and dry provisions are delivered to the SLN logistic depots, shore bases and fleet units by the various registered suppliers. However, special consideration must be given when delivering the cool room and cold room items to the long distance including the rural area logistic depot of the SLN.

In particular, coordinating logistic transports is significant to avoid duplicating vehicle movement in the logistics management of SLN when considering the shortage and repair status of vehicles available. Importantly, SLN can develop and implement a mobile application to check the scheduled vehicle movements for logistic transportation as a part of IoMT. Further, all logistic depots of SLN and Area Authorities can upload roadmove details through these applications for access to others when the situation demands to utilisation of vehicles for logistic transports.

Further, providing an opportunity to check the availability of spare parts or maintenance requirements within the logistic depots which can be enhanced through networking is a significant application of IoMT in the logistic management of the SLN. For instance, the interconnecting of all warehouses within all naval commands, SLN shall increase the effective and efficient sharing of resources including moving and non-moving items identification and distributing of them. Likewise, SLN could further improve existing logistic networking through the IoT introducing smart applications to enhance logistic management. It is important to highlight that, the Sri Lanka Army (SLA) has developed a considerable number of smart mobile applications as part of IoMT. Moreover, such applications include the refuelling authentication of staff cars as a unique mobile application. Also, interconnecting of SLN logistic depots established island-wide while providing authorized access facilities to check the availability of various logistic requirements and place the demand can avoid duplications and waste of resources. More specifically, Zhong et al, (2012) explained IoT has a wide range of applications in military logistics, including process function realisation and the unification of logistical functional areas such as warranty and military equipment maintenance, supply, traffic as well as transportation, quartermaster's office, medical services, etc.

For instance, the military logistics system's concept of network organization has its foundation in the organisational structure of logistics system monitoring. In particular, it typically consists of multiple branches that monitor distinct logistics functions because of varying needs for data generation and collection, analysis, and collection (Wang et al, 2018a, Wei et al, 2012). On the other hand, the use of IoT systems in logistics could also contribute to increased safety of logistic operations and below figure 2, indicates the basic application method of IoT for enhanced application of IoMT in the discipline of logistic management.

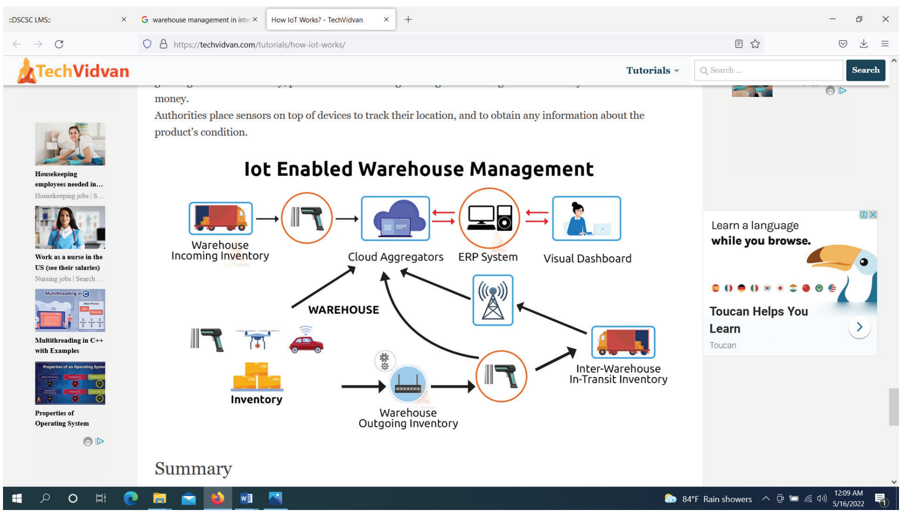

Figure 2: IoMT application in Military Warehouse Management System
Source: www.spiedigitallibrary.org

In particular, by preventing the joint transport of some goods, such as chemical components that might result in hazardous chemicals including explosive reactions, and parts of cryptography equipment that shouldn't be intercepted by an adversary, the use of IoMT devices for logistics could increase the safety of such logistic operations. Similarly, coordination of transportation within SLN logistic depots shall enhance the effective management of available vehicles. Furthermore, during the study, it was found that SLN is facing significant challenges in vehicle maintenance due to limited funds available for vehicle maintenance. However, it also found that, due to poor coordination vehicles are not effectively utilised for logistic transportation even within the particular naval command as well.

Moreover, it has been examined that from various areas of the country, vehicles are moving to the Colombo, Welisara, and Trincomalee logistic depots or area headquarters logistic depots to distribute SLN logistics. Importantly, it has been identified that SLN transport management systems can interconnect through networking by applying IoMT. Further, it will enable the reduction of duplicating vehicle movement while effectively utilising available resources. Also, the use of a Global Positioning System (GPS) technology to monitor vehicle movements applied in IoMT may enable to avoidance of malfunctions and route violations whilst enhancing transport efficiency in the SLN.

Fleet monitoring and maintenance can be represented by the SLN ships and ground vehicle fleets with onboard sensors that monitor performance and status. For example, they track vehicle status and subsystems and indicate when resupplying low-stock items is needed. Also, sensors would issue alerts, potentially reducing the risk of fatal failures. On the other hand, reducing maintenance staff, facilitating condition-based maintenance and on-demand spare purchasing, and lowering unexpected failures and needless part replacements are the goals. For instance, positions, status tracking, engine and speed status, overall engine hours, fuel economy, and weight and load sensors are all part of real-time fleet management. At present IoMT is used more effectively by developed navies such as the USA, EU countries and some ASIAN countries in the world for HRM. On the other hand, RFID systems for movement monitoring, fingerprints in access control and personal and official data repository management are more common IoMT applications. However, it has been observed that updating Human Resource Information (HRI) in SLN is still practised at a basic level when considering the facilities available under IoT. Also, updating valid HRI data is important and can reduce the time and paper consumed when implementing IoMT under logistic management. In particular, when naval persons are deployed outside the military premises for various purposes including nation-building activities, monitoring of them could be applied by introducing the RFID system. Importantly, troop monitoring in SLN is also vulnerable in the SLN context because a considerable number of naval persons are deployed outside the military premises to contribute to various nation-building activities.

Challenges faced by the SLN to enhance IoMT

More specifically, the study has found that SLN has indigenously developed or acquired IoMT in various disciplines under logistics management. However, it has been examined that the wide use of networking technology is not soundly practised. However, it has been identified that networking bases, fleet units and logistic depots for effectively sharing logistic management information at present do not apply the IoMT effectively SLN. In addition, the SLN shore establishments located in rural areas have fewer internet access facilities and poor networking systems. More specifically, due to the limited budgetary allocation, the acquisition of various devices related to the IoT also, affected for implementation of IoMT. Also, another point to consider is that fewer skilful human resources available within SLN also impacted the enhanced IoMT. In contrast, comparatively, there are very limited sailors serving in the SLN who know about IoT. On one hand, the study explored that during the recruitment process of SLN, there a fewer responses from the Z Generation IT-qualified candidates when conducting recruiting. Furthermore, the study found that there are very limited skilful candidates of the Z-Generation appearing for the recruiting interviews of SLN. Hence, it also hampers the empowering of IoT access in the SLN in future as well. It will cause an increased additional burden on SLN given conducting additional training for military persons for conversion with the IoT also adds extra training cost and time. In contrast, during the study, it was found that the use of smart devices for military purposes, the use of data links and the strengthening of the internet network have challenges within the Sri Lankan context due unavailability of their communication satellite to the country. However, indigenous skills and developed technology by the SLN can further extend and strengthen the networking capability to implement IoMT for better logistic management. In contrast, the identified unique challenges for the implementation of IoMT in the Sri Lankan context are summarised as indicated below:

1. Information security.
2. Availability of data/ internet with the required speed.
3. Poor network coverage around the country.
4. Cyber-attacks and hackers.
5. Tendency of continuing traditional methods.
6. Lack of budgetary allocation.
7. Less resource persons to handle IoMT.
8. Challenges for acquisition of new hardware and software.
9. Rapid change of IoT applications with new technological innovations.

Recommendations

The following recommendations were made considering the identified opportunities available and challenges facing for implementation of IoMT in the SLN to enhance logistics management:

1. Connecting all logistic depots through networking and providing opportunities to check item availability and place the demand.

2. Introduce mobile smart applications as suitable for SLN to search available items and place demand considering the way done by multinational companies like 'amazon'.

3. Installing GPS devices and monitoring vehicle movement.

4. SLN must strengthen the R & D enhance the application of IoMT and develop endogenously built smart applications, software and equipment related to IoMT.

5. Enhance the SLN recruitment by inducting IoT-qualified naval persons.

6. Introduce sound data storing and data security capabilities.

7. Implement sound cyber security policy.

8. Enhance fleet monitoring capability in SLN by introducing IoMT.

Conclusion

The IoMT refers to a wide range of devices with sophisticated physical sensing, learning and actuation capabilities that are connected to systems via virtual or cyber interfaces. Significantly, IoMT will play a key role in future military logistic management. Further, in SLN logistic operations IoMT is significant with numerous smart applications and networking all logistic depots. In particular, with the various military devices linked with IoMT, sensors, vehicles, robotics, human-wearable gadgets, biometrics, munitions, armour, weaponry, and other smart technology can be identified as the main key areas in logistic management. However, SLN has not given much priority to the cutting-edge advantages of IoT-based logistic operations in the past. On the other hand, technological innovation will continue to be important in the provision of military logistic management. In addition, understanding the information and the cyber domains will complement the logistic management greater extent in present and future scenarios. In addition, it has found that there are no sound actions have been taken to implement new R & D projects to enhance IoMT within the SLN in the present situation.

However, it is required to adjust the budgetary expenditures for the gradual development of IoMT in the SLN. Likewise, IoMT is a widely used concept in modern world logistic management and the application of IoMT will be rapidly increased. Furthermore, since SLN is in the process of rightsizing manpower, implementation of IoMT will enable the reduction of physical human involvement in numerous activities replacing IoT in the field of logistic management. However, continuous changes in IoT applications with new technology innovations, financial restrictions, shortage of skilful naval persons, the vulnerability of cybersecurity, and lack of hardware and software are the key challenges in SLN. Moreover, using the available facilities and resources while further extending them with indigenous development SLN could implement IoMT in an effective and efficient logistic management. Finally, it has explored that, implementation of IoMT in the SLN will enable a wide range of effective and efficient logistic management when the situation demands while applying the best resources management system.

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A DIGITAL MARKET PLACE FOR OPTIMIZING EMPTY TRUCK RETURN TRIPS IN SRI LANKA

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Abstract

An empty truck return trip is a constant problem for the Sri Lankan logistics sector, increasing its running expenses and environmental inefficiencies. Based on those, a digital marketplace is suggested to maximize the use of the available truck space by linking the Freight Owner to the truck operators. Real-time tracking, AI powered match load, and autographing the truck load orders are brought together. It simplifies the transaction by building confidence which will then enhance coordination amongst the participants. The suggested approach minimizes unnecessary truck use and maximizes taking use of the truck with environmental and financial advantages. Initial implementation involves basic verification, route matching, but the platform may be enhanced in the future with AI-based cargo validation and dynamic pricing models. This presents an opportunity for Sri Lanka's logistics sector to evolve into a more efficient and ultimately cost-effective transportation network, and that is its potential impact.

Keywords: Freight optimization, digital logistics, empty truck utilization

Introduction

Logistics is a crucial industry that plays an important role in Sri Lanka's national economy by supporting both domestic and international trade activities. The sector faces significant operational challenges, particularly the high incidence of empty return trips for trucks. These trips not only increase costs but also contribute to excessive fuel consumption and emissions due to wasted return trips. The industry is aware of these challenges, yet traditional route management practices fail to facilitate efficient return trips. If this issue is left unaddressed, it will persist in depleting resources, increasing operational costs, and worsening environmental impacts.

Based on this, this study proposes the creation of a digitalized platform for the optimization of empty truck return trips. If the platform can adopt digital improvements, routing operations and asset use may be improved in terms of costs and emissions. Implementation of this digitalized application will lead to a more sustainable and cost-effective truckload companies' logistics operation for truckload companies, shipping clients, and the economy. Operational efficiency of the platform would mutually benefit an environmentally and economically sustainable transportation system.

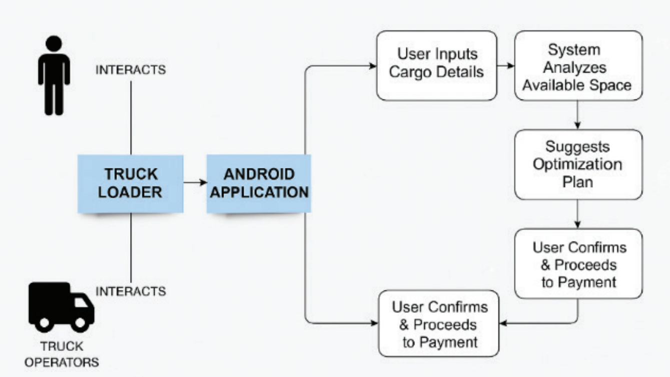

Fig. 1: Workflow of the Return Load Optimization Application

Figure 1: Workflow of the Return Load Optimization Application
Source: Author-designed UI/UX mockups illustrating the proposed system.

Literature Review

Efficient logistics systems and reducing operational costs depend on the optimization of the truck return trips (Fridman, 2022). However, the absence of real-time tracking and freight matching systems, combined with the inefficient utilization of trucks, remains a major challenge in Sri Lanka's transportation sector(Bemindu & Sharic, 2023). Through digitalization and intelligent transport solutions such as automated freight matching, empty truck trips can be significantly reduced, thereby enhancing sustainability (Teleroute, 2022). These platforms also function as real-time systems for monitoring truck load orders, effectively connecting transport operators with freight owners by providing visibility into available truck space (Bemindu & Sharic, 2023). Freight owners can input key cargo details such as weight, dimensions, and images (Sagar et al., 2020), while operators can register their fleets. Container utilization is further improved through load optimization algorithms, resulting in cost savings for all parties involved (Singh et al., 2021). Nevertheless, there exists in Sri Lanka a lack of a centralized system for which several empty trips continue to be present (Bemindu & Sharic, 2023). By shipping consolidation together with dynamic route planning, costs can be reduced further and travel without reason (Fridman, 2022), while real-time traffic monitoring helps reduce fuel consumption and emissions (Teleroute, 2022). While the travel salesman problem and the vehicle routing problem are valuable optimization models, these cannot be implemented due to a gap in infrastructure and a dispersed logistics network.

For example, freight exchange platforms allow the carriers to find available loads, see live freight rates, and communicate efficiently with the Freight Owners (Bemindu & Sharic, 2023). Sri Lanka has higher logistics costs and inefficient mileage due to the lack of a formalized freight marketplace.

Management of returnable containers is supported through reverse logistics that helps reduce emissions and costs (Lakhmi et al., 2022). Although not yet fully developed locally, intelligent systems, such as artificial intelligence and machine learning, can be usefully deployed towards optimizing fleet use and improving logistics transparency (Bemindu & Sharic, 2023).

Materials and Methods

This study adopts a design-based research approach to explore a digital solution for optimizing empty truck return journeys in Sri Lanka. The research commenced with an extensive review of both local and international literature to understand the operational challenges in freight logistics, particularly the issue of inefficient truck space utilization. Key concepts such as freight matching, route optimization, real-time tracking, and container utilization were identified as critical variables for improving logistics efficiency. These insights were used to conceptualize a mobile-based digital platform tailored to the Sri Lankan logistics environment. A benchmarking analysis of existing international digital freight platforms further guided the feature selection and system functionality, ensuring that the proposed solution aligns with both global best practices and local contextual needs.

To illustrate the envisioned platform and its core features, user interface mockups were designed using sample visuals. These mockups were purely illustrative and do not represent actual user data or a functional prototype. They were developed to convey how the proposed system would operate, including user registration, cargo entry, load matching, payment processing, and tracking dashboards. A comparative analysis was then conducted to evaluate traditional return logistics practices against the digital optimization approach, focusing on criteria such as space utilization, routing efficiency, cost, and environmental impact. Although primary data was not collected, the evaluation was supported through scenario-based assessments and literature-derived insights, forming the basis for proposing a contextually relevant and scalable digital logistics solution for Sri Lanka.

Results and Discussion

This study aims to introduce a digital platform for interconnecting truck operators with Freight Owners to facilitate the sharing of transportation services in Sri Lanka. The following section of the results and discussion elaborates on the key features of the application, supported by sample visuals and mockups to illustrate the user experience and functionality. This mobile app is for both Android and iOS systems and includes key logistics functionality such as real-time tracking, automated freight matching, and secure and third-party payments. Operators can register their vehicles by giving their vehicles, the weight the vehicle can carry, GPS positions of the vehicle live. This will make it possible for the drivers to post online requests, according to the location, cargo weight and in which price range an optimal logistics network is created.

Once users access the application, the experience begins with a minimalistic login interface tailored for Sri Lanka's mobile-first user base. The authentication process leads to a dashboard where Freight Owners can view matched trucks, and operators can manage cargo requests.

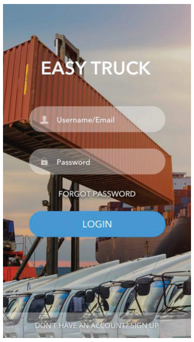

Figure 2: Interface of Login/ Signups

Source: Author-Designed UI/UX Mockups Illustrating the Proposed System

Users have an interface in the cargo space allocation interface to enter the details of the load, such as dimensions, weight, to calculate the remaining truck space. In addition, this provides the best possible utilization of the container as well as the return truck capacity, supporting logistics sustainability. The application further supports a streamlined experience with a simplified truck load order entry system, allowing image uploads and essential cargo details to be included for verification.

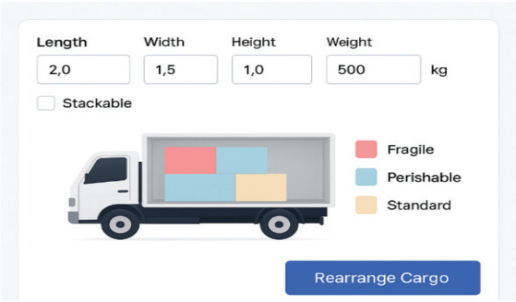

Figure 3: Cargo Space Allocation Interface with Physical Measures of Truck Loads

Source: Author-designed UI/UX mockups illustrating the proposed system

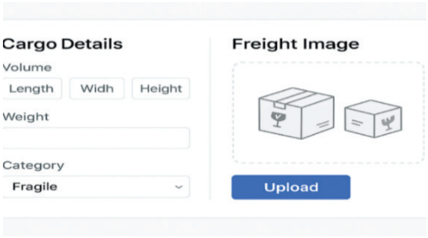

Figure 4: Truck load Orders Entry and Image Upload Portal

Source: Author-designed UI/UX mockups illustrating the proposed system

When the submission is completed, the users are given an interface that summarizes matched truck options, estimated delivery costs, and percentage cost savings versus conventional logistics. This will give clear information to provide the payment and will show the efficiency combined with the savings generated by the digital platform.

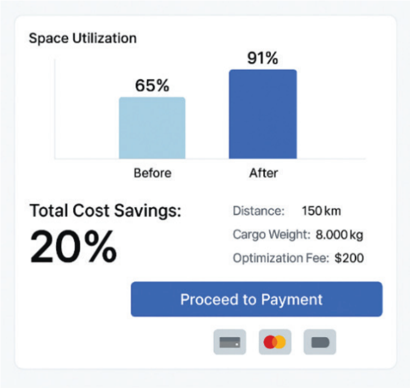

Figure 5: Application Output Summary with Payment Details
Source: Author-designed UI/UX mockups illustrating the proposed system

The algorithm used by the platform integrates current registrations with real-time truck load data and the calculated available space. It also enables temperature-sensitive and perishable goods transportation with real-time temperature monitoring of the cargo to achieve optimum cargo conditions and prevent the products.

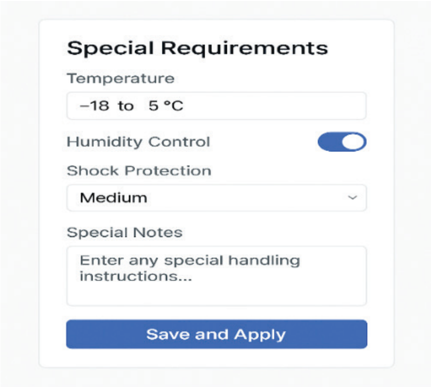

Figure 6: Temperature & Special Cargo Conditions Monitoring Interface
Source: Author-designed UI/UX mockups illustrating the proposed system

Notifications and alerts keep users informed throughout the delivery process, and profile features such as ratings help build trust and improve service quality.

User gets dashboards about which they can monitor and manage operations, as well as utilization rates and details about their cargo. Through this application, stakeholders can get a complete view of the progress of truck efficiency and load optimization and reduce waste, environmental damage.

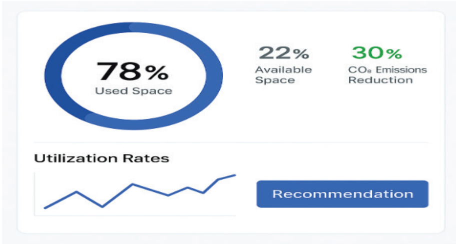

Figure 7: Optimized Utilization Rate Dashboard
Source: Author-designed UI/UX mockups illustrating the proposed system

The freight tracking interface offers real-time delivery analytics, system notifications, and tracking updates, while simultaneously assisting users in making decisions and adjusting routes accordingly.

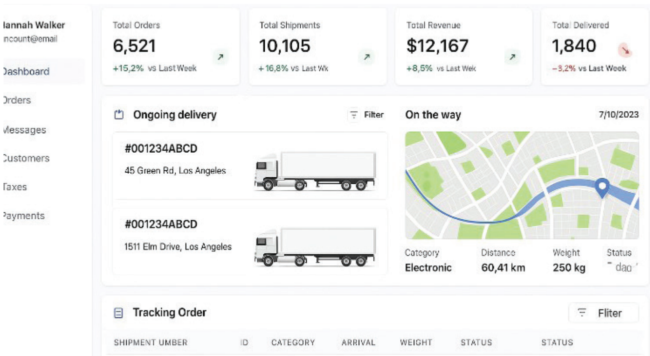

Figure 8: Freight Tracking Dashboard with Live Delivery Analytics and System Alerts
Source: Author-designed UI/UX mockups illustrating the proposed system

A comparison was first made between traditional return logistics and the digital optimization approach to help understand the transformation. Despite the existence of such other advanced technologies, the proposed system offers a significant improvement in space utilization, provides for dynamic fuel savings in routing, and provides interactive interfaces giving control to the users, which combine to produce cost efficiency and minimal environmental impact.

Criteria	Traditional Return Logistics	Proposed Optimization Application
Space Utilization	Low due to inefficient load planning	Maximized with tech-driven space allocation
Route Optimization	Static and manual	Dynamic real-time routing based on GPS
User Interface	No direct control by clients	Interactive dashboard with real-time inputs
Cost Efficiency	Higher fuel costs due to inefficiencies	Lower costs through optimized trips
Environmental Impact	More empty trips, higher emissions	Reduced carbon footprint with optimal loads

Table 1: Comparison of Traditional vs. Optimized Return Logistics
Source: Author's Analysis

The platform ensures that payments and transactions are handled through a secure and user-friendly process, facilitating smooth order confirmations and clear visibility of earnings. Designed for both Android and iOS devices, the application aims to cater to a wide segment of Sri Lanka's logistics network. However, despite these advancements, operational efficiency is still challenged by issues like poor and inaccurate documentation from Freight Owners. Currently, manual checks serve as the most effective means of addressing these issues, potentially rendering AI-based image verification unnecessary in the future. Features such as user ratings, streamlined verification steps, and real-time messaging enhance the connection and trust between Freight Owners and truck operators. The platform plans to evolve its pricing strategy by incorporating dynamic pricing for urgent truckload requests, supplemented by a discount and surcharge system. Furthermore, it envisions the establishment of adaptive cargo hubs along key transport routes, integrated with advanced technologies to foster a sustainable and efficient freight logistics ecosystem.

Conclusion

Research suggests a digital platform for optimizing empty truck fleet return travels to save corporate funds and reduce diesel consumption. Using the system truck operators connect to Freight Owners to increase truck space utilization, reduce travel, and reduce operational cost. Built with technological advancements in load matching, real-time tracking, and reliable verification of all truck load orders, this system supports a safe and efficient delivery experience. In addition, the platform reduces fuel consumption and carbon emissions and contributes to environmental benefits. However, challenges like truck load order verification and barriers to adoption need to be addressed. It is poised to transform Sri Lanka's freight logistics sector and contribute significantly to economic growth on a global scale.

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DIGITAL TRANSFORMATION IN SUPPLY CHAINS: LEVERAGING TECHNOLOGY FOR AGILITY AND EFFICIENCY

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Abstract

In today's fast changing global economy, supply chains are under more pressure to be quicker, more efficient, and responsive. The rise of digital technologies like the Internet of Things (IoT), Artificial Intelligence (AI), blockchain, big data analytics, and cloud computing is changing how supply chains work. These technologies are helping supply chains become more flexible and effective. This journal looks at how digital transformation is affecting supply chains. It focuses on the key technologies that are driving this change, the benefits businesses gain from using these technologies, the challenges they face, and what the future might hold. By using digital tools and systems, companies can improve their performance, lower their costs, and better meet the needs of their customers. For example, with IoT, businesses can track products in real-time, while AI can help predict demand and improve decision-making. Blockchain helps with security and transparency in transactions, and big data analytics allows companies to analyze large amounts of information to make smarter choices. Cloud computing makes it easier for businesses to store and access data from anywhere, improving efficiency.

Key words: Internet of Things (IoT), Artificial Intelligence (AI), blockchain, big data analytics, cloud computing

Introduction

Digital transformation is changing how supply chains work, making organizations more agile, responsive, and efficient. By using advanced technologies like artificial intelligence (AI), the Internet of Things (IoT), blockchain, and cloud computing, supply chains are becoming smarter and more focused on data. These technologies help businesses make faster decisions, improve operations, and gain better visibility throughout the entire supply chain.

AI, for example, helps companies predict demand and optimize inventory, while IoT enables real-time tracking of goods, allowing businesses to respond quickly to issues. Blockchain provides a secure way to track transactions and improve transparency, and cloud computing makes it easier for businesses to store and access data from anywhere, which is key for better decision- making.

As global markets grow more complex and unpredictable, digital tools help businesses handle disruptions and maintain high levels of service. These tools allow companies to react to changes in demand, supply shortages, or logistical challenges faster and more effectively.

In today's fast-paced world, digital transformation is not just a choice but a necessity. Organizations that embrace these technologies can stay ahead of the competition, adapt to changes quickly, and continue to provide excellent service. Those who fail to adopt digital tools may struggle to keep up as the market evolves. Therefore, integrating digital technologies into supply chains is crucial for businesses to thrive in a rapidly changing environment.

Key Technologies Driving Digital Supply Chains

1. Internet of Things (IoT)

The Internet of Things (IoT) plays a critical role in modern supply chains. IoT devices, such as sensors on products and vehicles, help businesses track goods in real-time. They monitor storage conditions, such as temperature or humidity, and can send alerts if any issues arise. These devices provide detailed and continuous updates, which improve visibility across the supply chain. This results in more accurate stock management, reduces the chances of product damage or loss during transportation, and helps prevent delays. Overall, IoT technology enhances operational efficiency by giving companies the tools to act quickly when problems arise.

2. Artificial Intelligence (AI) and Machine Learning (ML)

Artificial Intelligence (AI) and Machine Learning (ML) are advanced technologies that help businesses use large amounts of data to make more informed decisions. These tools can predict customer demand, optimize delivery routes, detect fraud, and even automate many decision-making processes. AI and ML also enable businesses to foresee potential disruptions, such as supply shortages or transportation delays, allowing them to react quickly to avoid negative impacts. By enhancing forecasting accuracy and improving operations, AI and ML increase overall efficiency and reduce operational risks.

3. Blockchain Technology

Blockchain technology offers a secure, transparent, and unchangeable record of transactions throughout the supply chain. It ensures that every party involved can access the same reliable information, improving visibility and trust. Blockchain minimizes the risk of fraud, which is especially important in industries where security and traceability are critical. By providing a trustworthy record of transactions, blockchain also helps companies meet legal and safety regulations and fosters stronger relationships between supply chain partners.

4. Big Data Analytics

Big data analytics tools collect and analyze vast amounts of structured and unstructured data from multiple sources. This data helps businesses understand customer preferences, evaluate supplier performance, and optimize operations. With the insights gained from big data, companies can make smarter decisions, mitigate risks, and enhance their strategies. By analyzing trends and patterns, businesses can identify opportunities for improvement and adjust to changing market demands more effectively.

5. Cloud Computing

Cloud computing platforms are essential for modern supply chains. They allow teams to access and share data from anywhere, fostering collaboration across locations. Cloud services reduce IT costs, increase scalability, and support real-time decision-making. This flexibility helps supply chains become more responsive and adaptable to change. By making information easily accessible and enabling quicker updates, cloud computing enhances the ability of businesses to stay agile and manage their operations more effectively.

Strategic Benefits of Digital Supply Chains

1. Enhanced Agility

Digital supply chains provide businesses with the ability to quickly adapt to changing market conditions, such as shifts in customer demand or unexpected disruptions like delays and shortages. With real-time data and advanced planning tools, companies can make faster and more informed decisions. This agility allows businesses to adjust their strategies rapidly, ensuring they can continue to meet customer expectations and remain competitive in a fast-paced environment. Whether responding to a sudden surge in demand or managing a supply chain interruption, digital technologies help businesses remain flexible and responsive.

2. Improved Efficiency

Automation plays a significant role in improving the efficiency of digital supply chains. Technologies like Robotic Process Automation (RPA) can handle repetitive and time-consuming tasks with greater speed and accuracy than human workers. This reduces the likelihood of human error, saves valuable time, and lowers operational costs. By automating routine tasks, employees can focus on higher-value activities that require creativity and decision-making, further boosting the overall productivity of the business. This increase in efficiency helps streamline operations, making supply chains faster, more cost-effective, and less prone to mistakes.

3. Increased Transparency

Digital supply chains offer full visibility from start to finish, meaning that businesses and their partners can track products and materials at every stage of the process. This transparency improves communication and ensures that everyone involved in the supply chain is on the same page. It helps prevent misunderstandings and reduces the chances of errors or delays. Moreover, with clear visibility, companies can better manage their relationships with customers and suppliers, improving trust. Additionally, digital tools help businesses comply with industry regulations and governmental rules, as they provide a clear and accurate record of all supply chain activities.

4. Better Customer Experience

Customers today expect quick service, up-to-date information, and personalized experiences. Digital supply chains are crucial in meeting these expectations. By providing real- time delivery tracking and updates, businesses can keep customers informed throughout the entire process. Moreover, digital systems help companies address problems swiftly, whether it's an order delay or inventory issue, leading to quicker resolutions. Customization and personalization are also easier with digital tools, allowing businesses to meet the unique needs of individual customers. This results in higher customer satisfaction, repeat business, and greater loyalty, all of which are essential in today's competitive market.

5. Sustainability and Risk Management

Digital systems can also contribute to a company's sustainability efforts by reducing waste, optimizing energy use, and tracking the environmental impact of supply chain activities. For example, advanced analytics can help identify inefficiencies, such as overproduction or excessive energy use, allowing businesses to make changes that are more eco-friendly. Furthermore, digital tools enhance risk management by identifying potential issues early on, such as supplier delays or transportation problems. With this information, companies can take proactive steps to mitigate these risks, preventing disruptions and ensuring that supply chains continue to run smoothly. This not only helps businesses avoid costly problems but also supports their long-term sustainability goals.

Challenges in Implementing Digital Transformation

1. High Initial Investment

One of the biggest challenges in implementing digital transformation is the high initial investment required. Companies need to purchase new hardware, install specialized software, and train employees. Additionally, the systems must be integrated across various departments and functions, which can be costly. For small and medium-sized businesses, these upfront expenses can be a significant barrier. They may struggle to secure the necessary funding for these investments, which slows down the digital transformation process and limits their ability to adopt new technologies.

2. Data Security and Privacy

As businesses increasingly rely on connected devices and share more data across platforms, the risk of cyberattacks, hacking, and data breaches also grows. Protecting sensitive data becomes a top priority. Companies must invest in strong cybersecurity measures, such as encryption and secure networks, to safeguard their information. Additionally, they need to ensure compliance with data privacy regulations, which vary by country and region. Failure to implement adequate security and privacy protocols can lead to significant financial losses, damage to reputation, and legal consequences.

3. Organizational Resistance

Employees may resist the changes brought about by digital transformation, especially if they fear job loss or feel uncomfortable with new technology. Resistance to change is a common challenge that can delay or even block the transformation process. To address this, companies need to provide comprehensive training to help employees understand and use new tools. Clear communication about the benefits of digital transformation and how it will enhance their work can help alleviate concerns. Additionally, offering strong support throughout the transition can foster a more positive environment and encourage employee buy-in.

4. Integration Complexity

Many companies operate with legacy systems that may not easily integrate with modern digital tools. Merging these older systems with new technologies can be complex, time-consuming, and costly. It often requires careful planning, extensive testing, and technical expertise to ensure that everything works seamlessly together. Businesses must invest in skilled IT professionals or consultants who can navigate these integration challenges, and sometimes it can take longer than expected to achieve full system compatibility.

5. Regulatory and Compliance Issues

Companies that operate in multiple countries face additional challenges with regulatory and compliance issues. Different countries have different laws and regulations related to data storage, privacy, and digital activities. For instance, data protection laws like the General Data Protection Regulation (GDPR) in the European Union require businesses to take specific actions to protect customer data. Navigating these varying rules can be complicated, but it is essential for businesses to ensure compliance to avoid legal issues, fines, or damage to their reputation. Developing a global compliance strategy that addresses regional differences is crucial for successful digital transformation.

Case Studies of Digital Transformation

1. Amazon

Amazon is a global leader in using technology to improve supply chain operations. It uses Artificial Intelligence (AI), robots, Internet of Things (IoT) devices, and big data to make its warehouses and delivery systems faster and smarter. AI helps Amazon understand customer preferences and suggest products they may like. Data from warehouses and transport systems helps the company manage inventory better and deliver products more quickly and efficiently.

2. Maersk and IBM Blockchain

Maersk, one of the largest shipping companies, partnered with IBM to develop Tradelines, a digital platform based on blockchain technology. This system helps track shipments, reduce paperwork, and speed up customs processes. By sharing real-time data with all partners in the shipping process, Tradelines increases transparency and reduces delays, making international trade more efficient.

3. Walmart

Walmart uses blockchain to track the journey of food from farm to store. This helps improve food safety and makes it easier to identify and remove unsafe products. Walmart also uses IoT sensors and AI to monitor storage conditions, predict customer demand, and keep shelves stocked. This technology helps reduce waste and ensure customers find what they need.

4. DHL

DHL has introduced smart warehouses that use robots and data tools to improve storage and delivery. The company also uses Augmented Reality (AR) and Virtual Reality (VR) to train employees more effectively. These technologies help workers learn faster and improve the way tasks are done, making the supply chain more efficient and reliable.

Future Trends in Digital Supply Chains

1. Hyper-automation

Hyper-automation refers to the integration of advanced technologies, such as AI, machine learning, smart devices, and robotics, to fully automate complex tasks within the supply chain. This trend is expected to revolutionize the way work is done, making processes faster, more accurate, and less reliant on human intervention. By automating more aspects of the supply chain, businesses can boost productivity, reduce human errors, and lower operational costs. Hyper- automation will also allow organizations to streamline operations and focus on strategic decision- making rather than manual tasks, ultimately enhancing efficiency and profitability.

2. Digital Twins

A digital twin is a virtual model of a physical object, system, or process, used to simulate and analyze its behavior in real time. This technology allows businesses to test new ideas, predict potential problems, and improve overall performance without disrupting actual operations. For instance, a digital twin of a manufacturing plant can help managers foresee equipment breakdowns, optimize production schedules, and fine-tune processes before making real-world changes. By using digital twins, companies can enhance their decision-making, reduce downtime, and improve the design and functionality of their operations.

3. 5G Connectivity

The rollout of 5G networks will provide faster internet speeds and more reliable connections, significantly enhancing data sharing between devices and systems. With 5G, businesses will be able to transmit large amounts of data quickly, enabling real-time monitoring and decision-making in supply chains. The high-speed network will support the use of smart devices, such as sensors and RFID tags, that will collect and analyze data in real time. As a result, businesses can make more informed decisions, respond quickly to changing market conditions, and improve the efficiency and responsiveness of their supply chains.

4. Sustainability and Circular Economy

As sustainability becomes increasingly important, digital tools are helping businesses adopt more eco-friendly practices. Technologies like big data analytics and blockchain allow companies to track and reduce the environmental impact of their supply chains, improve waste management, and promote recycling. By focusing on sustainability, businesses can reduce their carbon footprint, minimize waste, and promote a circular economy where products and materials are reused, remanufactured, and recycled. These efforts not only benefit the environment but also help companies comply with regulatory standards and enhance their brand image by appealing to environmentally conscious consumers.

5. AI Driven Decision Making

Artificial intelligence is set to play an even more significant role in decision-making across supply chains in the future. AI will be used to analyze vast amounts of data and provide intelligent recommendations to optimize processes, from sourcing raw materials to delivering finished products. By using AI-driven insights, businesses can better predict demand, identify risks, and respond more quickly to disruptions. This ability to make data-driven decisions will enhance operational efficiency, reduce costs, and help businesses stay competitive in a rapidly changing marketplace. As AI technology evolves, its impact on decision-making in supply chains will continue to grow, driving innovation and improving overall performance.

Conclusion

In conclusion, digital transformation has become essential for modern supply chains. It allows companies to be faster, smarter, and more flexible, helping them keep up with the ever- changing business world. Through the use of advanced technologies, businesses can make better decisions, save time and money, and quickly adapt to customer demands or unforeseen challenges. While there are some difficulties, such as high costs and the need for employee training, the benefits in the long run far outweigh these challenges.

To make this transformation easier, companies should develop a clear plan and encourage collaboration across teams. As new technologies continue to evolve, supply chains will become more efficient, eco-friendly, and focused on meeting customer expectations. Businesses that embrace digital transformation now will be better positioned to succeed in the future.

In simple terms, adopting digital tools today helps companies stay competitive and strong in the years to come. The shift to digital will allow businesses to adapt to future changes, provide better service, and ensure they remain ahead of the competition. Those who wait to make this change may find it more difficult to catch up, making it crucial for companies to act now in order to thrive in the future.

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BIG DATA ANALYTICS FOR ENHANCED SUPPLY CHAIN VISIBILITY: HOW DATA ANALYTICS CAN IMPROVE DECISION MAKING AND RESPONSIVENESS IN SUPPLY CHAINS

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Abstract

Big data analytics has emerged as a transformative force in supply chain management, offering unprecedented capabilities to integrate, process, and analyse vast, heterogeneous datasets for actionable insights. This article examines how big data analytics can enhance supply chain visibility, decision-making, and responsiveness. Through a comprehensive literature review, it traces the evolution from descriptive to predictive and prescriptive analytics, and explores theoretical underpinnings such as the extended SCOR model and the ResourceBased View. It discusses data collection and integration techniques including IoT sensors, ERP systems, RFID, and social media and analytical methods that convert raw data into strategic intelligence. The study highlights technological platforms such as cloud computing, artificial intelligence, and machine learning that support scalable, real-time analytics. Case studies across retail, manufacturing, logistics, and Sri Lankan contexts illustrate practical applications, demonstrating improvements in tracking, risk management, and demand forecasting. Key challenges data quality, integration barriers, cybersecurity, and cultural resistance are identified, with mitigation strategies proposed, including robust ETL processes, data governance frameworks, and organizational change initiatives. Looking ahead, emerging trends such as blockchain, digital twins, and ethical analytics are explored, emphasizing sustainability and regulatory considerations. The article concludes with strategic recommendations for practitioners and policymakers to invest in integrated analytics platforms, foster digital skills, and support collaborative research, ensuring resilient, transparent, and agile supply chains in a volatile global economy.

Keywords: Big data analytics, supply chain visibility

Introduction

Big Data Analytics has developed as a transformative tool in contemporary supply chain management, allowing organizations to process and examine massive amounts of data to gain actionable insights. As Infosys BPM (2021) explains, in today's dynamic business setting, big data analytics includes the integration, processing, and examination of massive, varied datasets, both organised and unorganised, to expose hidden patterns, trends, and associations that drive calculated decision making. Mucci and Styker (2024) highlights that, as companies wrestle with market volatility and growing global competition, leveraging these progressive analytical abilities has become critical to enhancing Supply chain visibility, operational efficiency, reducing costs, and fostering agility in supply chain operations.

Supply chain visibility is the capacity to track and screen every section of the supply chain in real time, from raw material procurement to final product distribution. Vollmer (2023) Illustrates how this wide-ranging transparency is vital for effective decision-making and receptiveness because it provides a complete view of the whole supply chain ecosystem.

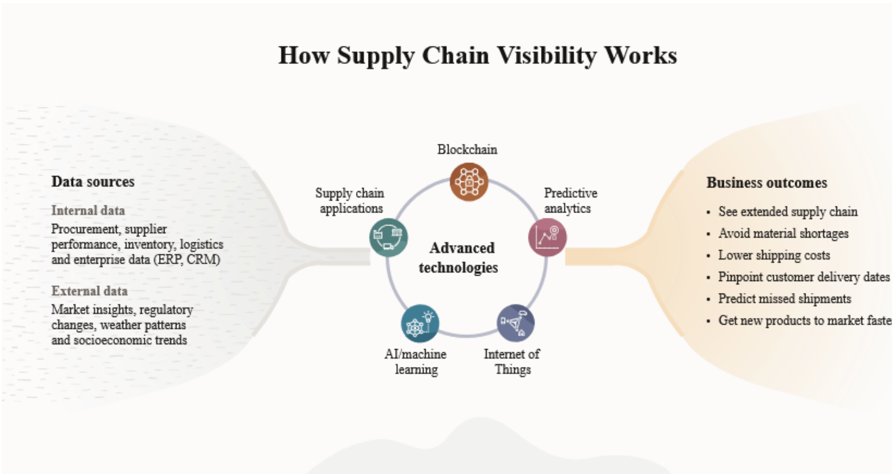

Figure 1: How Supply Chain Visibility Works
Source: www.oracle.com/lk/scm/supply-chain-visibility/

Lasanthika and Wickramasinghe (2020) explains that, with improved visibility, organizations are allowed to proactively manage risks, perceive and mitigate possible disruptions, and streamline processes by guaranteeing seamless communication amongst all stakeholders. By integrating data from numerous sources, such as IoT devices, ERP systems, and real-time analytics platforms, companies can optimize inventory management, improve demand forecasting, and continue a competitive edge in fast-changing market conditions (Digital Matter, 2024).

The main objective of this essay is to discover how big data analytics can be harnessed to enhance supply chain visibility, thereby refining decision-making and receptiveness in supply chain operations. Specifically, the essay aims to answer key questions like, how can big data analytics be combined effectively into existing supply chain systems? What best practices and advanced technological solutions are accessible to enable real-time monitoring and predictive analytics in supply chains? Additionally, the essay will scrutinise the challenges organizations face during the application of these technologies, such as issues connected to data superiority, integration blocks, and cybersecurity risks.

Background and Literature Review

The historical development of supply chain analytics imitates a transformative journey from outdated, paper-based systems to today's extremely digitized and unified networks. Over the past few decades, companies have progressively integrated digital technologies into their operations, moving from basic data collection to advanced analytics capable of predicting and real-time decision making. Initially, supply chain analytics attentive on descriptive statistics and intermittent reporting, but the advent of digital technologies such as RFID, ERP systems, and ultimately cloud computing has transformed the landscape. As highlighted by KPMG, the conjunction of digital and physical substructures has fostered rooted intelligence within supply chains, enabling a more active and reactive approach to managing supply chain processes (Perera, 2023). This development was not linear but was somewhat of an iterative development that saw substantial milestones, including the development of Industry 4.0, which further enhanced the digital transformation of supply chains by integrating IoT, AI, and machine learning.

Lakpura, Hansika, Fernando. et al., (2021) explains that the theoretical frameworks underpinning the integration of big data analytics in supply chain management have evolved concurrently with technological advancements. Academic research, as compiled in various studies accessible via ResearchGate, outlines several models and theories that provide a foundation for understanding how data-driven approaches can optimize supply chain operations. One such model is the Supply Chain Operations Reference (SCOR) model, which has been extended to incorporate big data analytics by linking operational processes with performance metrics.

Moreover, the Resource-Based View (RBV) of the firm has been useful in explaining how unique analytical abilities can create sustainable competitive advantages in supply chain management. Scholars have also explored the application of data processing theories, which argue that improved data analytics abilities enable organizations to improve processes and respond to multifaceted and rapidly changing environments. These theoretical foundations are critical, as they provide organised approaches for taking part in diverse data sources, managing doubt, and fostering novelty in supply chain practices (Sachin and Bandara, 2021).

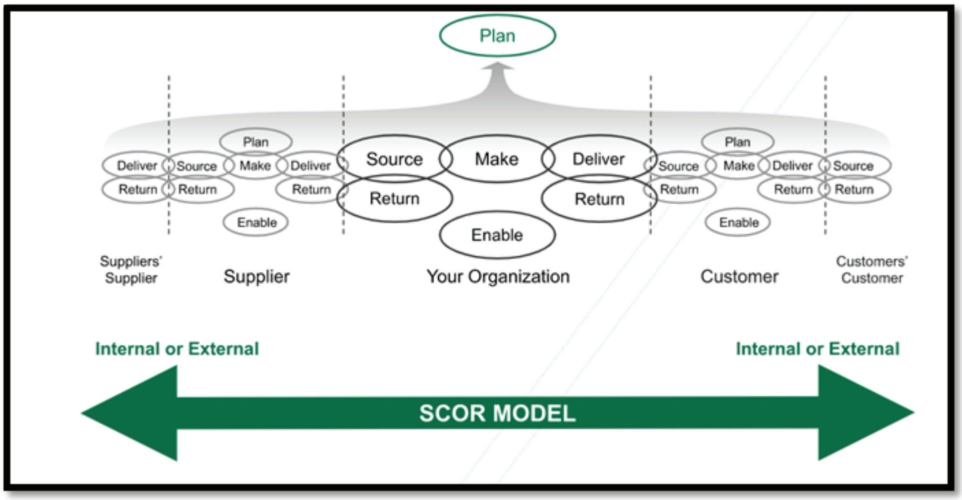

Figure 3: Supply Chain Operations Reference (SCOR) Model
Source: Supply Chain Council, 1996

Recent developments in data analytics have intensely redesigned supply chain practices, reflecting a paradigm shift towards predictive and prescriptive analytics. Present trends specify that the disposition of AI-driven algorithms, machine learning models, and real-time data processing platforms has enabled organizations to not only comprehend past performance but also to estimate future trends and proactively mitigate risks. Acropolium's insights into top logistics technology tendencies reveal that big data analytics now plays a dominant role in facilitating real-time supply chain monitoring, enabling predictive preservation, and improving overall receptiveness. These progressions have led to more agile supply chains that can rapidly adapt to disturbances, optimize inventory levels, and improve customer service (Dmytro Tymoshchenko, 2025). Moreover, the incorporation of digital twin technologies permits companies to simulate supply chain situations and assess the influence of various strategies in a simulated environment, thereby fostering invention and continuous development.

Further combining these trends is the role of universal digital platforms and cloud computing, which have democratized entry to advanced analytics tools. Leading technology companies such as IBM have donated pointedly to this transformation by providing strong big data analytics platforms that support scalable and secure data processing. These platforms have not only enhanced operational efficiency but have also allowed more strategic, data-driven methods to decision-making, which is vital for maintaining competitive advantage in a progressively volatile market (Mucci and Stryker Cole, 2024). Similarly, Oracle's stress on supply chain visibility underscores the importance of integrating data across multiple systems to create a united, translucent view of supply chain operations, which is important for effective risk management and receptiveness (Vollmer, 2023).

Big Data Analytics Tools and Techniques

1. Data Collection and Integration

Big data analytics in supply chains depend on strong data gathering and integration. Supply chains yield data from various sources, including IoT devices, ERP systems, social media, and RFID tags. IoT sensors in transportation fleets capture real-time asset circumstances and environmental data. ERP systems combine transactional data on procurement, inventory, and order completion. Social media and customer feedback provide unstructured data that exposes market trends and consumer intent.

Digital Matter has underlined that combining these diverse data sources includes sophisticated data integration techniques such as data warehousing, real-time data streaming, and the use of middleware solutions to ensure unified data flow between disparate systems (How IoT has Enhanced Supply Chain Visibility - Digital Matter, 2024). By employing homogenous protocols and data normalization practices, organizations can consolidate this multilayered data into a unified platform that facilitates wide-ranging analytics, thereby supporting conversant decision-making across the supply chains (Mucci and Stryker Cole, 2024).

2. Analytical Methods

After data gathering and integrating, the next step is organising analytical methods for actionable intuitions, which fall into three categories: descriptive, predictive, and prescriptive analytics. Descriptive analytics analyzes past data to identify trends and patterns. Predictive analytics uses statistical models and machine learning to estimate future trends based on past data, allowing for proactive decision-making. Prescriptive analytics endorses specific actions to optimize outcomes.

GEP outlines those prescriptive analytics is particularly crucial in supply chain contexts, as it not only predicts future scenarios but also suggests practical resolutions to mitigate potential dangers and capitalize on developing opportunities (Prescriptive Analytics in Supply Chain - Meaning, Ways & Challenges | GEP Blogs, 2023). These methods work synergistically to convert raw data into a strategic asset that drives efficiency, optimizes resource allocation, and enhances operational agility. This multi-layered analytical approach empowers organizations to not just understand what has happened or what might happen but also to determine the best course of action to achieve desired outcomes (Chen, 2024).

3. Technological Platforms

Contemporary technological platforms, like cloud computing, AI, and ML, significantly improve big data analytics scalability and efficiency. Cloud computing proposes flexible infrastructure to stock and process large data capacities, meeting the demands of extensive supply chain operations. This scalability lets businesses adjust analytics competencies based on real-time needs, ensuring optimal performance and cost-effectiveness.

Infosys BPM has researched how cloud-based platforms back the integration of big data analytics by contributing seamless data storage, processing power, and cooperative environments that foster novelty across the supply chain (Infosys BPM, 2021). Furthermore, AI and ML algorithms are employed to analyse data at unparalleled speeds, discovering complex patterns that remain hidden using outdated analytical methods. These technologies allow real-time decision-making, predictive maintenance, and dynamic optimization of supply chain processes. IBM's work in this field highlights the role of AI and ML in changing raw data into actionable intelligence that drives operational excellence (Mucci and Styker, 2024).

Furthermore, the incorporation of AI with cloud platforms not only improves scalability but also guarantees that analytics resolutions are secure, resilient, and flexible to evolving business needs. By automating monotonous tasks and facilitating deeper insights through progressive analytics, these technological platforms help businesses maintain a competitive edge in a progressively complex and volatile global market (Chen, 2024).

Impact on Supply Chain Visibility and Decision Making

Big data analytics has intensely transformed supply chain visibility and decision-making by allowing companies to harness real-time data, anticipate disturbances, and drive strategic actions (The Benefits of Real-Time Tracking in Supply Chain Management, 2025). At the lead of this transformation is real-time monitoring and understanding. Modern supply chains depend on progressive tracking systems that integrate data from sensors, RFID tags, and IoT devices to deliver a prompt view of goods as they move through the logistics network. Oracle highlights that such real-time tracking not only advances operational agility but also allows decision-makers to retort swiftly to developing issues, thereby diminishing delays and optimizing resource distribution (Joseph Tsidulko, 2024). In addition, platforms devoted to real-time monitoring allow managers to imagine complex data sets through active dashboards, making it easier to detect irregularities and trends as they happen (The Benefits Of Real-Time Tracking And Monitoring In Supply Chain Management - Britts Imperial 2025, 2023).

In the area of risk management and awareness, big data analytics plays a vital role in predicting and mitigating supply chain risks. Maersk points out that by leveraging predictive analytics, organizations can simulate various disruption scenarios and implement proactive actions to mitigate possible risks (Sanaa Jabeen Mughal, 2024a). This competence is particularly valued in volatile markets, where quick shifts in demand, supplier unpredictability, or logistical disruptions can have substantial financial repercussions(Data Analytics and Risk Management: Unlocking the Potential in the Sri Lankan Business Market, 2023). Through unremitting monitoring and data analysis, companies can classify emerging risks, such as bottlenecks or shipment interruptions, and rapidly adapt their strategies to maintain service levels. Furthermore, risk management outlines that integrated data analytics facilitates conversant decisions, allowing businesses to balance cost, speed, and risk more efficiently (Deb Marotta, 2024).

Improved decision-making processes signify another important benefit of integrating big data analytics into supply chain management. Traditional decision-making often depends on intermittent reports and historical data analysis, which could delay the response to market deviations. Today, big data changes these procedures by providing actionable insights that notify both strategic and tactical decisions. Studies have revealed that companies using data-driven methods experience progress in inventory management and demand forecasting, leading to more efficient production preparation and reduced operational expenses (Mashud et al., 2021). By applying methods such as machine learning and advanced statistical modelling, organizations can predict upcoming demand patterns with greater precision, regulate inventory levels proactively, and optimize the general supply chain flow. These improved capabilities not only streamline operations but also foster a competitive advantage in quickly changing settings (Data-Driven Demand Forecasting in Manufacturing) (Snowflake, 2025).

Case Studies and Practical Applications

Big data analytics has cemented the way for transformative developments in supply chain operations, as established by a range of real-world case studies and practical applications. In many trades, companies have positively harnessed advanced analytics to suggestively boost supply chain visibility and efficiency. For example, Acropolium highlights numerous accomplishments where logistics firms have combined GPS tracking, real-time dashboards, and data incorporation tools to monitor the movement of goods. These ingenuities have not only minimised transit times but have also lessened losses and improved customer satisfaction by providing precise, on-demand visibility of resources (Oleksii Glib, 2023).

When associating the application of big data analytics across diverse sectors, a clear difference in strategies and outcomes arises. In the retail sector, companies' emphasis on demand forecasting and inventory optimisation to moderate stockouts and overstock conditions. In contrast, manufacturing businesses leverage predictive maintenance and process optimisation to rationalise production and reduce downtime. The logistics sector, however, places a finer focus on real-time tracking and route optimisation to ensure apt deliveries. KPMG's research highlights that while each sector has exclusive challenges and wants, the fundamental principles of data-driven decision-making making such as enhanced prediction accuracy, risk mitigation, and operational efficiency, remain consistent. This cross-industry analysis discloses that best practices, including the use of predictive analytics and integrated dashboards, can be adapted across sectors to drive comparable benefits, though they must be custom-made to the specific operational settings and regulatory environments of each industry (Supply chain trends 2024: The digital shake-up, 2024).

Further intuitions can be drawn from case studies in specific industries. For example, researches demonstrate how a telecommunications company in Sri Lanka has leveraged big data analytics to improve its marketing strategies and progress supply chain receptiveness. The company combined diverse data sources from customer behaviour to network performance metrics to optimize supply chain processes and attain a competitive edge in a rapidly developing market (Senavirathne, 2022). Similarly, another publication shows how manufacturing companies in Sri Lanka have accepted analytical techniques to improve decision-making, leading to noteworthy improvements in inventory management and demand forecasting(Liyanage and Kumarage, 2021).

Outside of these sector-specific examples, wider case studies deliver actionable lessons for future strategies. A study available in MDPI offers understandings from a case study in Kandy, Sri Lanka, where big data analytics was used to measure urban sustainability and resource allocation. Although the emphasis was on urban planning, the methodologies and data incorporation techniques are transferable to supply chain management, stressing the importance of inclusive data collection and cross-functional partnership (Dissanayake et al., 2020). Moreover, past case studies from sources like the Wageningen University repository disclose that early acceptance of data-driven policies in local communities paved the way for contemporary applications, highlighting the long-term assistance of investing in digital infrastructure and analytical competencies.

Challenges, Limitations, and Mitigation Strategies

1. Data Quality and Integration Issues

Big data analytics in supply chain management is frequently challenged by matters related to data superiority and integration. One of the main hurdles is the existence of data silos, where data is stored in remote systems that do not simply communicate with one another. This disintegration can lead to discrepancies in data, making it problematic for organizations to get a united and accurate opinion of their supply chain. For example, disparate data sources reaching from transactional ERP systems to sensor data from IoT devices often use dissimilar formats and standards, which generates significant integration barriers. These matters can result in redundant data, errors, and interruptions in decision-making procedures (Harding, 2013a). Advanced data integration strategies, such as engaging robust ETL (Extract, Transform, Load) processes and middleware solutions, are vital to overcoming these problems and ensuring that data from multiple sources can be precisely combined and analysed (Beauden John, 2025).

2. Security and Privacy Concerns

Security and privacy continue to be critical fears in the realm of big data analytics. As organizations progressively rely on digital data, the risks related to data breaches and cyberattacks become more noticeable. Subtle information, such as customer data and proprietary supply chain metrics, can be unprotected if not properly safeguarded. Acquiescence with data safety regulations adds another layer of difficulty. Companies must devise robust cybersecurity procedures, including encryption, multi-factor authentication, and incessant monitoring to protect against illegal access (Vorecol Editorial Team., 2024). Additionally, following compliance requirements demands ongoing audits and updates to security protocols, which can be resource-intensive but are crucial for maintaining trust and operational honesty.

3. Organizational and Cultural Hurdles

Outside of technical challenges, organizations face noteworthy internal challenges when applying big data analytics solutions. Resistance to change is a common barrier, frequently rooted in a long-lasting organizational culture that favours traditional decision-making procedures over data-driven methods. Employees may be cautious to adopt new technologies due to doubts of redundancy or due to a lack of understanding with advanced analytical tools. This resistance is combined with a shortage of analytical expertise within many organizations, mainly in regions where digital transformation is still developing. Additionally, strategies such as cross-functional partnership and incentivizing data literateness can help mitigate resistance and build a more agile and receptive organizational culture(boohene, 2010).

4. Integrated Approach and Future Strategies

Addressing these tasks holistically is vital for the effective application of big data analytics in supply chains. Organizations must capitalise not only on advanced technological resolutions but also on social transformation initiatives. For data quality and incorporation, establishing consistent data governance frameworks and leveraging contemporary integration platforms can streamline the merging of diverse data sources (Harding, 2013b). In terms of security, proactive actions such as real-time threat monitoring and obedience to international compliance standards are crucial (Vorecol Editorial Team., 2024). Organizationally, fostering a culture that welcomes digital conversion through leadership engagement, continuous training, and cross-functional partnership is key to overcoming resistance and building healthy analytical capabilities. By integrating these technical, security, and cultural strategies, businesses can not only improve their operational efficiency but also create a long-lasting competitive advantage in a progressively data-centric business environment.

Future Trends and Innovations

1. Emerging Technologies

Evolving technologies such as blockchain, digital twins, and advanced IoT are transforming supply chain analytics by allowing real-time visibility and improved data integrity. Blockchain technology proposes a decentralized ledger that ensures the legitimacy and traceability of transactions, thereby minimising fraud and enhancing trust among investors. Digital twins, which are virtual copies of physical supply chains, permit companies to simulate operations and forecast outcomes under numerous scenarios. This digital mirroring aids in recognising bottlenecks and enhancing processes without unsettling actual operations. Moreover, progressive IoT devices collect granular data from sensors and link devices across the supply chain, providing nonstop monitoring and instant insights. Maersk highlights that these technologies are crucial in driving resilience and transparency in contemporary supply chains, contributing a noteworthy competitive edge in volatile markets (Sanaa Jabeen Mughal, 2024). Moreover, industry specialists highlight that integrating these technologies aids organizations break traditional data silos and substitute a data-driven culture, leading to more agile and healthy supply chain systems. Furthermore, research on advanced supply chain analytics proves that the meeting of digital twins, IoT, and blockchain not only improves visibility but also improves sensitivity in complex, data-driven environments (Louis Owusu-Berko, 2025).

2. Predictive Analytics and AI Integration

The blend of predictive analytics with artificial intelligence will alter supply chain responsiveness. Predictive modelling leverages past data to forecast future trends, while AI algorithms unceasingly learn from new data inputs to improve these predictions. This dynamic mixture allows organizations to forecast demand fluctuations, enhance inventory levels, and proactively manage potential disturbances. Studies specify that predictive analytics, improved by machine learning models, can significantly progress correctness in forecasting and facilitate more agile decision-making processes (Silva Bimsara, 2025). Additionally, insights disclose that AI-driven analytics is allowing companies to expose hidden patterns within huge datasets, thus nurturing more informed strategic and tactical decisions. This transformation is not partial to forecasting; AI also contributes to automating monotonous decisions and enhancing operational efficiency through continuous, real-time learning, positioning organizations to adapt to changing market situations.

3. Sustainability and Ethical Considerations

As supply chains progress, sustainability and ethical considerations have converted to be integral to the decision-making process. Analytics plays a key role in promoting sustainable practices by enhancing resource use, reducing waste, and minimizing environmental effects. For instance, sustainable supply chain management models influence data to assess the carbon footprint of operations, identify inadequacies, and implement greener logistics practices. Research on sustainable supply chain management, mainly studies focusing on businesses such as tea production, highlights how analytics can improve sustainability while ensuring compliance with environmental regulations (Kleindorfer, Singhal and Van Wassenhove, 2005).

Moreover, ethical decision-making is progressively reinforced by transparent data practices. By warranting data accuracy and protecting consumer privacy, businesses can build trust and uphold compliance with evolving global data protection standards. Ethical contemplations also extend to the accountable use of AI, ensuring that algorithms are free from bias and contribute positively to society. Initiatives that integrate ethics into data analytics frameworks help businesses steer complex regulatory settings while endorsing fair and sustainable practices. This ethical lens is vital for long-term sustainability and for protecting stakeholder interests in a rapidly digitizing world (Abeysekara, Wang and Kuruppuarachchi, 2019).

Conclusion and Recommendations

The incorporation of big data analytics into supply chain management has appeared as a transformative force, suggestively enhancing visibility, decision-making, and receptiveness across diverse sectors. By leveraging massive datasets and progressive analytical tools, organizations have achieved unparalleled transparency in tracking goods, predicting demand, and enhancing operations. This convergence of digital technologies from IoT sensors and ERP systems to AI-driven analytical models has enabled real-time monitoring and agile replies to market variations, thereby minimising operational risks and cumulative overall efficiency(Yapa, 2018). These key understandings underscore the serious role that big data analytics plays in determining a resilient and modest supply chain in a progressively volatile global economy.

Looking forward, strategic endorsements for practitioners and policymakers center on embracing technology holistically. First, it is authoritative to invest in scalable, cloud-based analytics stages that integrate data across all sides of the supply chain. Such platforms not only enable real-time decision-making but also improve the ability to predict and mitigate disturbances, as highlighted by business leaders like Oracle (Joseph Tsidulko, 2024). Additionally, policymakers should support the development of regulatory contexts that balance novelty with data security and privacy. Encouraging teamwork between the public and private divisions can foster a vigorous digital substructure that supports advanced analytics, thereby increasing national competitiveness. Emphasizing digital knowledge and continuous skill growth within the personnel will further help organizations overcome social and organizational hurdles, safeguarding that the aids of digital transformation are fully understood.

Furthermore, future research should emphasise several key areas to withstand the momentum of innovation in supply chain competence. Researchers are encouraged to explore the incorporation of developing technologies, such as blockchain, digital twins, and advanced IoT devices, with outdated supply chain management practices. These studies could bring deeper insights into how decentralized ledger skills, for example, improve data veracity and reduce fraud across multi-tiered supply networks (Louis Owusu-Berko, 2025b). In addition, there is a persistent need to improve predictive analytics models by mixing artificial intelligence and machine learning, which could further improve the forecasting accuracy and flexibility of supply chain systems (Silva Bimsara, 2025). Sustainability and ethical contemplations also warrant further study; research that assesses the environmental impact of supply chain processes and identifies policies for greener logistics will be serious as companies strive to decrease their carbon footprints in alignment with global sustainability goals.

Moreover, continuous examination of the interaction between regulatory frameworks and technological novelty remains vital. Policymakers and industry investors should consider starting cooperative research initiatives that address challenges connected to data security, compliance, and cross-border data flows, particularly in regions where digital conversion is rapidly developing. By integrating these understandings into strategic planning and policy preparation, organizations can ensure that their supply chains not only continue to be efficient and resilient but also contribute to wider economic and social purposes.

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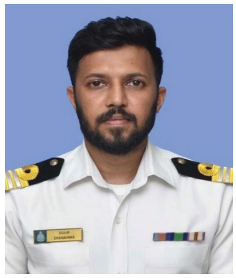
THE IMPACT OF DIGITAL TRANSFORMATION ON SUPPLY CHAIN MANAGEMENT



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Abstract

In the contemporary age of high-speed and technology-driven business environment, digitalization is impacting supply chain management (SCM) in a significant manner. The paper elaborates on how the integration of advanced digital technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), blockchain, cloud computing, and big data analytics are changing the manner in which supply chains are being managed. These technologies are enabling companies to maximize visibility across the supply chain, real-time decision-making, reduced operating costs, and increase overall efficiency (PHONG, 2019). Technology today allows firms to track materials and products in real-time, predict demand more accurately, manage inventory more effectively, and respond quickly to interruptions. Furthermore, automation and smart technologies are streamlining logistics, procurement, and manufacturing processes, and this is enhancing customer service and competitiveness. However, the journey to digital change is by no means smooth. It is usually accompanied by high implementation costs, integration issues, data privacy concerns, and insufficient digital competencies within the workforce. In this article, the benefits of digital change in supply chains, its limitations, and provides insights into how organizations can successfully adapt to and endure in a more digitally interconnected society are discussed.

Keywords: Digital transformation, supply chain management, digital technology, artificial intelligence, automation

Definition of Digital Transformation

Digital transformation is the deliberate alignment of digital technologies in all aspects of a business to improve operations, enhance customer value, and drive innovation. It is not merely adopting new software or automating procedures; it is an end-to-end rethinking of how an organization operates, delivers products or services, and engages with stakeholders. Technologies such as Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), blockchain, robotics, cloud computing, and big data analytics form the backbone of digital transformation (E. Shoikova, 2021).

In supply chain management, digital transformation enables end-to-end visibility, real-time communication, predictive analytics, and more informed decision-making. It helps organizations optimize inventory, reduce lead times, enhance demand forecasting, and respond quickly to disruptions or changing customer preferences. Moreover, digital transformation facilitates collaboration between suppliers, manufacturers, distributors, and retailers, and makes the entire supply chain more agile and resilient.

Moreover, digital transformation also comprises a cultural and organizational change. It requires new leadership tactics, upskilling of employees, and a mentality open to constant change and modernization. As industries become more economical and customer expectations increase, digital transformation is no longer optional it is a strategic requirement for long-term progress and sustainability.

Key Technologies in Digital Transformation

Digital transformation is being driven by a host of advanced technologies that are transforming the way businesses operate, especially in supply chain management (SCM). These technologies enable businesses to be more resilient, efficient, and responsive to customers' needs. Some of the most significant technologies that are part of digital transformation include (Johan Røed Steen, 2020):

1. Internet of Things (IoT)

Internet of Things (IoT) refers to the network of physical devices, such as sensors, RFID tags, GPS trackers, and smart machines that can collect and share information over the internet. IoT in supply chain management enables the tracking of goods movements in real time, inventory monitoring, and transportation route management.

For example, temperature, where products are being located, and delays detected by sensors fitted in delivery vehicles allow companies to control product quality (especially cold chains like foods and medicines) and customer satisfaction. With all the segments of the supply chain connected, IoT allows for improved visibility, eliminates mistakes, and helps companies to make decisions through real-time information.

2. Artificial Intelligence (AI) and Machine Learning (ML)

AI and ML are two of the most groundbreaking technologies for digital supply chains. They allow businesses to analyze huge amounts of data within a limited time and make smart decisions. AI can be used for demand forecasting, predictive maintenance, warehouse automation, and customer service chat bots.

In the supply chain, artificial intelligence systems can anticipate future demand for products based on a sales history of patterns, market patterns, and even weather. This reduces overstocking and stock outs. Machine learning, continuously learns from new data, becoming smarter and making more intelligent decisions with time. This leads to better forecasting, better inventory planning, and reduced operating costs.

3. Big Data and Analytics

Big data refers to the large volumes of structured and unstructured data from various sources such as customer orders, supplier information, shipment details, and social media. Analytics software helps firms to analyze the data and gain profound insights.

In the supply chain, big data analytics improves performance by uncovering bottlenecks, optimizing delivery routes, and interpreting customer buying behaviors. For example, Amazon and Walmart use big data to analyze customer behavior and tailor inventories to fit. Predictive analytics based on big data also helps firms prepare for disruptions by forecasting potential risks and developing alternatives.

4. Cloud Computing

Cloud computing gives enterprises the ability to store, share, and use data and programs via the internet rather than a local server. Cloud computing is a big contributor to digital transformation, delivering flexibility, scalability, and cost advantages.

In supply chains, cloud platforms enable real-time collaboration between different partners, suppliers, manufacturers, logistics firms, and retailers without geographical locations. It also makes it easy to store and retrieve data centrally, improving communication and decision-making. Companies can grow their operations or shrink them based on demand without excessive infrastructure costs. Cloud-based systems also make it easy to integrate other technologies like IoT and AI, hence making them robust.

5. Blockchain Technology

Blockchain is an immutable, decentralized ledger that stores transactions in an open and transparent format. Blockchain delivers data integrity and trust among different parties engaged in a supply chain.

Blockchain is particularly applicable to tracking origin of goods, verifying supplier authenticity, and excluding fraud. As an example in food manufacturing, blockchain can follow food from farmer to consumer, verifying food quality and safety. In the pharmaceutical industry, it excludes counterfeit drugs by verifying product passage through supply chains. Smart contracts, which are digital contracts programmed onto a blockchains are also used for automatic payment and timely delivery with no paperwork or dispute.

6. Robotic Process Automation (RPA)

RPA utilizes software bots to automate tedious and manual tasks such as data entry, handling invoices, and updating stock levels. RPA reduces human mistakes, speeds up operations, and lowers operational costs.

In supply chains, RPA can be used to automate procurement operations, manage communications with suppliers, and process orders in an efficient manner. Since back-office functions are automated, companies can spend more time on strategy-focused activities like building strong relationships with suppliers and customer experience.

7. Digital Twins

A digital twin is a virtual replica of a physical entity, process, or system. In supply chain management, digital twins may be employed to simulate entire supply networks to try out scenarios and predict outcomes prior to their happening in the real world

For example, a company can create a digital twin of its warehouse and test how layout changes would affect efficiency or simulate supply chain disruptions (Example, port shutdowns or raw material shortages) to plan effective responses. This technology facilitates planning, risk management, and innovation.

8. Advanced Automation and Robotics

More advanced supply chains are now including the use of robotics for handling functions like packing, sorting, and shipping of products within warehouses. They are equipped with sensors and artificial intelligence to work with human beings, increasing the speed and accuracy.

Automated guided vehicles (AGVs) and drones are also used for material handling and last-mile delivery, especially in large scale operations. Robotics not only decreases labor costs but also minimizes the likelihood of human error and enhances workplace safety.

Digital transformation is driven by a robust mix of emerging technologies, each offering unique benefits to supply chain operations. With these technologies integrated, they create smarter, adaptive, and more efficient supply chains. Digital transformations enable these companies to attain a significant competitive advantage with better data-driven decision-making, enhanced customer satisfaction, and greater flexibility in an ever-changing market. However, to be able to realize the benefits fully, organizations will also have to invest in training, infrastructure, and change management to implement successfully.

Benefits of Digital Transformation for Supply Chain Management (SCM)

Digital transformation is revolutionizing the landscape of supply chain management, offering a number of benefits that enhance operational efficiency, customer satisfaction, and business success. With the integration of digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, big data analytics, and cloud computing, organizations can gain significant benefits across the supply chain. The key benefits of digital transformation of SCM are explained below (A K M Ezazul Haque, 2020):

1. **Improved Visibility and Transparency**

One of the greatest advantages of digital transformation is improved supply chain visibility. With IoT, RFID, and cloud-based systems, companies can track in real time from the factory floor to the final customer. This visibility allows companies to monitor performance, identify delays, and respond in advance. Blockchain technology also increases trust and traceability by providing a secure, tamper-proof record of each transaction.

2. **Enhanced Efficiency and Productivity**

Technology helps in the automation of manual and redundant processes, such as order processing, tracking of inventory, and monitoring shipments. Automation reduces human errors, speeds up operations, and enables staff to focus more on strategic tasks. For instance, Robotic Process Automation (RPA) and Artificial Intelligence (AI) can demand forecast, procurement, and supplier communication more efficiently than human tasks.

3. **Enhanced Decision-Making by Data Analytics**

Digital transformation enables the collection and analysis of vast amounts of data from multiple sources. Big data analytics and AI enable businesses to turn this raw data into actionable insights. This leads to better decision-making in inventory management, supplier selection, route optimization, and risk management. Predictive analytics also enables anticipation of market changes and supply disruptions, allowing businesses to prepare in advance.

4. Cost Reduction

Automation, efficient logistics, and good forecasting minimize waste and excessive spending. For example, with proper demand forecasting and real-time tracking of inventory, firms can avoid overstocking or understocking, which leads to significant savings. Additionally, improved route optimization with the use of GPS and artificial intelligence technology saves fuel cost and delivery time.

5. Greater Agility and Flexibility

Flexibility is crucial these days, given its unstable and competitive business environment. Digital supply chains can instantly respond to fluctuations in demand, disruptions in suppliers, or even world events. Cloud-based systems facilitate instant coordination and communication between partners, whereas AI-powered systems can dynamically move production and inventories. Such flexibility allows firms to remain agile and competitive.

6. Improved Customer Satisfaction

Digital transformation helps companies deliver better and faster service. Real-time order tracking, faster response times, and personalized services enhance the overall customer experience. When customers receive accurate delivery estimates and can monitor their orders, it builds trust and loyalty.

7. Sustainability and Compliance

Digital technology can also support sustainable supply chain operations. Companies can use, for example, analytics for lower energy consumption, minimizing waste, and ethical procurement. Blockchain technologies can ensure that products meet ethical and regulatory standards, enhancing brand reputation and compliance with global legislation.

Digital transformation brings many benefits that allow firms to build wiser, more flexible, and customer-centric supply chains. With changing markets all over the world, businesses that embrace digital innovation will be more capable of achieving operational excellence and lasting success.

Challenges of Implementing Digital Transformation in SCM

While digital transformation is a great benefit to supply chain management, implementing it is not simple. Most organizations, especially small and medium-sized enterprises (SMEs), face a number of challenges that complicate or inhibit the process (Özden Özkanlısoy, 2021):

1. **High Initial Investment Costs**

Among these, one major hindrance is the costly adaptation of advanced technologies. It requires significant investment to carry out AI, IoT, cloud technology, and automation software. It requires an enormous amount of investment in hardware, software, training, and infrastructure. To small-budget business firms, it is a heavy obstacle.

2. **Digital Talent and Skills Lack**

Digital transformation also requires a skilled workforce that can manage and operate new technologies. Most organizations are beset by a shortage of professionals with experience in data analytics, cyber security, and digital systems. Training existing employees or hiring new ones adds cost and complexity.

3. **Integration with Legacy Systems**

The majority of the firms are still relying on old or legacy systems, which are not digital platform compatible. It could become difficult, labor-intensive, and risky to link new technology to these kinds of systems if data is siloes or of uneven form.

4. **Cyber security Threats**

As supply chains grow more interconnected and data-dependent, they are at greater risk of cyber-attacks. Protecting sensitive customer and business information from breaches is a new concern that requires advanced security protocols and constant monitoring.

5. **Resistance to Change**

Digital transformation involves workflow, cultural, and management style adjustments. Workers, and even senior executives, may resist these changes due to fear of losing their jobs, being unfamiliar with technology, or being accustomed to existing procedures.

To overcome these hurdles, careful planning, strong leadership, and a clear digital strategy are required. Companies must balance technological progress with risk management and staff training to realize a successful transformation.

Future of Digital Transformation and SCM

The future of digital transformation in supply chain management (SCM) will be dynamic, intelligent, and highly networked. As technology continues to evolve, supply chains will mature from reactive systems to proactive and predictive networks, with the capacity to adapt in real time to global demands and disruptions (Anon., 2016).

Emerging technologies such as Artificial Intelligence (AI), 5G, edge computing, and digital twins will lead this change. AI and machine learning will power predictive analytics, which will enable supply chains to foresee demand, recognize risks, and optimize operations with minimal human involvement. Digital twins are virtual replicas of physical assets will allow companies to simulate different scenarios, improving decision-making and operational planning.

In addition, the use of blockchain will enhance transparency and trust, especially in global and complex supply chains. It will enhance product authenticity, minimize fraud, and make compliance with regulations easier. The development of autonomous systems, including drones and autonomous vehicles, will revolutionize logistics and last-mile delivery, making supply chains faster and more efficient.

Sustainability will also become a leading concern. Digital technologies will help in monitoring environmental impact, reducing waste, and enforcing ethical sourcing. Future supply chains won't just be digital; they'll be intelligent, resilient, and sustainable. Companies that continue to invest in digital transformation will be better positioned to thrive in a competitive and fast-changing global market.

Conclusion

Supply chain management is being revolutionized by digital transformation, which allows organizations to function more efficiently, make data-driven decisions, and respond in a timely manner to the changing needs of the market. Through the implementation of better technologies such as AI, IoT, cloud computing, blockchain, and big data analytics, supply chains are becoming agile, transparent, and customer-focused.

The benefits are self-evident: greater visibility, cost reduction, enhanced collaboration, and enhanced risk management. The journey towards digital transformation is not without its challenges. High implementation cost, security concerns, integration challenges, and resistance to change must be managed carefully in order to be able to successfully transform.

In the future, supply chains will be shaped by intelligent automation, real-time exchange of data, and sustainable development. Companies implementing digital transformation not only gain operational performance but will also become competitive in an increasingly digitalized and globalized economy.

In short, digital transformation is no longer an option; it is a strategic necessity for building resilient, responsive, and future-proof supply chains. Those organizations that make investments in the right technologies and develop a clear digital strategy will be well equipped to handle the complexities of modern supply chain environments.

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CYBER SECURITY IN DIGITAL SUPPLY CHAINS: ADDRESSING VULNERABILITIES IN A HYPER CONNECTED WORLD

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Abstract

This study examines the cyber security challenges in digital supply chains within an increasingly interconnected world. It highlights critical vulnerabilities such as ransomware, compromised software, stolen credentials, and insufficient visibility into third-party security measures. Real world breaches, including Solar Winds and AT&T, are used to demonstrate cascading operational and reputational risks. The study evaluates risk management frameworks, compliance with GDPR, PCI DSS, and HIPAA, and newer regulations like DORA and NIS2. It also investigates how advanced technologies such as AI, block chain, and continuous monitoring can help mitigate these threats. Best practices are provided to improve resilience, emphasizing the importance of risk assessment, vendor audits, joint security drills, and public-private partnerships. The findings advocate a proactive, collaborative, and technology-driven approach to cyber security. This ensures digital supply chains remain protected from evolving cyber threats and helps organizations build sustainable operations in a hyper connected environment.

Keywords: Cyber security, digital supply chain

Introduction

As global supply chains become more digitized, the risk of cyber-attacks increases dramatically. Organizations now rely heavily on external vendors, cloud platforms, and interconnected IT systems, creating a complex environment that is vulnerable to cyber threats. The infamous Solar Winds breach exemplifies how a single point of vulnerability can compromise multiple organizations across sectors (Smith, 2022; Li and Lee, 2021; Brown, 2023).

Common cyber threats include ransomware attacks, the use of compromised software, credential theft, and insufficient third-party vendor visibility. Ransomware, in particular, is known for locking vital systems and demanding payments, disrupting entire operations (Thompson, 2020; Zhao and Kumar, 2022). The risks are intensified by regulatory pressures and evolving compliance requirements, making cyber security not just a technical issue but a strategic business concern (Singh and Davis, 2022; Larson and Watson, 2023).

Key Vulnerabilities

Digital supply chains are exposed to multiple threats due to their reliance on digital infrastructure such as ERP systems, IoT devices, cloud computing, and mobile applications (Li and Lee, 2021).

1. Ransomware Threats

Ransomware is one of the most damaging threats, locking access to critical systems and data. These attacks often lead to downtime, revenue loss, and reputational damage (Thompson, 2020; Zhao and Kumar, 2022).

2. Compromised Software

Hackers may infiltrate third-party software, injecting malicious code that spreads across connected systems. This is especially dangerous in environments with weak code validation practices (Ng and Patel, 2021; Carter and Lewis, 2023).

3. Stolen Credentials

Cyber attackers gain unauthorized access by stealing employee login details, often through phishing or key logging software (Thompson, 2020; Zhao and Kumar, 2022).

4. Lack of Visibility

Many companies have poor visibility into their vendors' cyber security practices, leaving blind spots that attackers can exploit (Ng and Patel, 2021; Carter and Lewis, 2023).

5. Inadequate Security Practices

Weak practices such as failure to patch systems, reuse of user accounts, and poor system audits allow cyber threats to persist (Edwards, 2020; Thompson, 2020).

Methodology

This study is based on a comprehensive review of over 30 academic articles, industry reports, and case studies including the Solar Winds and AT&T breaches. Risk assessment matrices were applied to evaluate threat severity and likelihood. The study also reviewed compliance standards and assessed technologies like AI and block chain for their risk mitigation potential (Williams, 2021; Ghosh and Matthews, 2023).

Impact of Cyber security Incidents

1. Operational Disruptions

Breaches often lead to system outages and cloud service failures, causing halted operations and unhappy customers (Thomas and Wilson, 2022; Moore and Harris, 2023).

2. Financial Losses

Industries lose millions annually from disruptions and fraud. For example, average losses in 2023 reached $82 million in sectors like aerospace and finance (Jackson and Edwards, 2021; Thomas and Wilson, 2022).

3. Reputational Damage

Failing to secure digital assets harms stakeholder trust and brand value, possibly resulting in long-term business setbacks (Singh and Davis, 2022; Larson and Watson, 2023).

4. Legal and Regulatory Consequences

Companies can face serious legal repercussions and fines for non-compliance with cyber security regulations such as GDPR or HIPAA (O'Brien and Clark, 2022; Zhang and Smith, 2021).

Best Practices for Cyber security

1. Risk Management Frameworks

Risk matrics help prioritize threats based on likelihood and impact. Regular compliance audits and crisis management plans are critical to reduce exposure (Ghosh and Matthews, 2023; Jones and Roberts, 2020).

2. Advanced Security Technologies

Encryption, tokenization, and AI-driven security tools can strengthen defenses against data theft and malware (Carter and Bennett, 2021; Ghosh and Matthews, 2023).

3. Joint Security Exercises

Cyber security drills with suppliers and government bodies help prepare for real-world incidents (Larson and Watson, 2023; Jones and Roberts, 2020).

4. Continuous Monitoring and Improvement

Given the evolving nature of cyber threats, continuous monitoring of all digital touch points is essential (Moore and Harris, 2023).

5. Public-Private Partnerships

Collaborations with government agencies improve threat intelligence sharing and regulation alignment (Jones and Roberts, 2020).

6. Lessons from Real-World Incidents

Success stories, such as AI-based breach prevention by a global manufacturer, highlight the value of proactive defenses (Jones and Roberts, 2020).

Regulatory and Compliance Frameworks

1. Overview

Cyber security regulations ensure businesses and their vendors adhere to data protection and operational resilience standards.

2. Key Regulations

a. GDPR mandates shared responsibility between organizations and third parties in case of data breaches (Harris and Walker, 2022).

b. PCI DSS requires firms to validate their vendors' security posture in financial transactions (Harris and Walker, 2022).

c. HIPAA extends security accountability to third parties handling patient data (Kumar and Singh, 2023).

3. Emerging Regulations

a. DORA enhances the resilience of financial entities through mandatory third-party security assessments (Williams and Rogers, 2021).

b. NIS2 Directive expands the scope of cyber security obligations to more industries (Williams and Rogers, 2021).

Conclusion

The dynamic nature of cyber threats, coupled with increasingly complex supply chains, necessitates a strategic and adaptive cyber security posture. Businesses must integrate risk management frameworks, leverage emerging technologies, and adhere to global regulations to build resilient digital ecosystems. Cross-sector collaboration and real-time threat detection are key to mitigating future risks and ensuring sustainable operations in an interconnected world (Jones and Roberts, 2020; Carter and Bennett, 2021; Ghosh and Matthews, 2023).

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CHALLENGES OF IMPLEMENTING DIGITAL TRANSFORMATION IN SUPPLY CHAIN MANAGEMENT

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Abstract

This study provides an in-depth examination of the multifaceted challenges organizations encounter when implementing digital transformation in supply chain management (SCM). Drawing upon extensive secondary research, the analysis identifies four primary obstacle categories: technological limitations, organizational resistance, financial constraints, and external environmental factors. The study reveals that while advanced technologies like IOT, AI, and blockchain offer transformative potential, their successful implementation requires addressing deeply rooted systemic issues. Through comparative case studies and industry data, the paper demonstrates how leading organizations have navigated these challenges, offering actionable insights for practitioners. The findings emphasize that digital SCM transformation is not merely a technological endeavor but a complex organizational change process requiring strategic alignment across all business functions.

Keywords: Digital Transformation, supply chain management, industry 4.0, organizational resistance, technology adoption

Introduction

1. The Digital Imperative in Modern SCM

Contemporary supply chains operate in an era of unprecedented volatility, where traditional linear models have become obsolete. Digital transformation represents a paradigm shift from reactive to predictive supply chain management, enabled by real-time data analytics and intelligent automation (Ivanov et al., 2022). The COVID-19 pandemic served as a catalyst, exposing vulnerabilities in analog supply chains while demonstrating the resilience of digitally mature organizations. For instance, companies with advanced digital capabilities experienced 50% shorter recovery times during supply chain disruptions (McKinsey, 2022). This resilience stems from three key digital capabilities: end-to-end visibility, predictive analytics, and automated decision-making. Organizations that successfully implemented digital transformation initiatives reported 45% higher customer satisfaction rates and 30% lower operational costs compared to their analog counterparts (Deloitte, 2023). However, despite these compelling benefits, approximately 70% of digital transformation projects fail to achieve their intended outcomes (Boston Consulting Group, 2023), highlighting the significant challenges inherent in this process.

2. Research Scope and Objectives

This study aims to:

a. Systematically analyze the technological, organizational, financial, and environmental barriers to digital SCM implementation.

b. Evaluate successful transformation strategies across diverse industries.

c. Develop a framework for overcoming implementation challenges

The research focuses on medium to large enterprises across manufacturing, retail, and logistics sectors, drawing upon data from 2018-2023 to capture recent technological advancements and pandemic-related lessons. The study employs a multi-method approach, combining a systematic literature review with in-depth case study analysis of both successful and failed digital transformation initiatives. By examining these cases through the lens of established theoretical frameworks, the paper provides both academic and practical insights into the digital transformation process.

Literature Review

1. Theoretical Foundations

The Technology-Organization-Environment (TOE) framework provides a robust lens for examining digital transformation challenges (Tornatzky & Fleischer, 1990). This model identifies three contextual domains influencing technology adoption:

a. **Technological context**. Examines how the characteristics of available technologies and their capabilities affect adoption decisions. This includes factors such as compatibility with existing systems, perceived benefits, and complexity of implementation.

b. **Organizational context**. Focuses on internal firm characteristics including size, structure, human resources, and innovation culture. Larger organizations often have more resources but may face greater inertia, while smaller firms may be more agile but lack necessary capital.

c. **Environmental context**. Considers external factors such as industry characteristics, competitive pressures, and regulatory landscape that influence adoption decisions.

Recent studies have extended this framework to include financial factors as a distinct dimension (AlNuaimi et al., 2022), recognizing the substantial capital requirements of digital initiatives. This expanded model highlights how budgetary constraints, return on investment calculations, and funding availability significantly impact digital transformation outcomes. The financial dimension is particularly crucial in SCM transformations, which often require substantial upfront investments in both technology and human capital.

2. Evolution of Digital SCM Technologies

The progression from basic automation to cognitive supply chains has occurred through four distinct phases:

a. **Digitization (1990s-2000s)**. The initial transition from paper-based to digital records, characterized by the adoption of basic computing systems and electronic data interchange (EDI). This phase focused primarily on improving record-keeping efficiency rather than transforming operational processes.

b. **Digitalization (2000s-2010s)**. The automation of processes through enterprise resource planning (ERP) systems and early supply chain management software. This period saw the integration of various business functions and the emergence of more sophisticated planning tools.

c. **Digital transformation (2010s-present)**. The integration of advanced technologies including artificial intelligence (AI), machine learning (ML), Internet of Things (IoT), and blockchain. This phase represents a fundamental rethinking of supply chain operations, enabling real-time visibility, predictive analytics, and autonomous decision-making.

d. **Autonomous SCM (emerging)**. The development of self-learning, self-correcting supply networks that can anticipate disruptions and automatically optimize operations. While still in its infancy, this phase promises to revolutionize supply chain management through fully automated, intelligent systems.

This evolution has created a widening capability gap between early adopters and lagging organizations, with significant competitive implications (Wieland, 2021). Companies that successfully navigate the digital transformation process gain substantial advantages in terms of operational efficiency, customer responsiveness, and risk mitigation, while those that fail to adapt risk becoming increasingly uncompetitive in their respective markets.

3. Methodology

This research employs a systematic literature review methodology, analyzing 78 peer-reviewed articles and 32 industry reports published between 2018-2023. The study incorporates:

a. **Thematic analysis** of implementation challenges, identifying common patterns and unique cases across different industries and organizational contexts.

b. **Comparative case studies** of successful transformations, examining both positive examples and cautionary tales to derive best practices.

c. **Cross-industry benchmarking** of digital maturity levels, comparing adoption rates and implementation strategies across different sectors.

Data sources include academic databases (Scopus, Web of Science), consulting firm reports (McKinsey, Gartner), and corporate disclosures from leading adopters. The research methodology follows a rigorous process of source identification, screening, eligibility assessment, and data extraction to ensure comprehensive coverage of relevant literature while maintaining academic rigor. Particular attention was paid to recent developments (post-2020) to capture the accelerated digital transformation trends resulting from the COVID-19 pandemic.

4. Technological Challenges

a. Legacy System Limitations

Outdated IT infrastructure presents the most formidable technical barrier to digital transformation, with three specific manifestations:

(1) **Integration complexity**. 63% of organizations report significant difficulties connecting new technologies with legacy ERP systems (Gartner, 2023). The average large enterprise maintains 89 distinct SCM applications, creating data silos and process fragmentation that hinder end-to-end visibility. These integration challenges often require costly middleware solutions or complete system replacements, both of which can significantly delay transformation timelines.

(2) **Data quality issues**. Manual data entry errors and inconsistent data formats cost businesses an estimated $3.1 trillion annually in the US alone (IBM, 2021). Legacy systems often lack the data governance frameworks needed for advanced analytics, resulting in unreliable insights and poor decision-making. Many organizations find that their data is either incomplete, inconsistent, or stored in incompatible formats that cannot be easily utilized by modern analytical tools.

(3) Scalability constraints. Traditional systems cannot handle the volume and velocity of modern supply chain data. For example, IoT-enabled supply chains generate 50x more data points than conventional systems (Deloitte, 2022), overwhelming legacy architectures not designed for such workloads. This limitation becomes particularly acute when organizations attempt to implement real-time tracking or predictive analytics capabilities.

These technical limitations often create a vicious cycle where organizations cannot modernize because their systems are outdated, but cannot update their systems because they lack the digital capabilities to manage the transition effectively. Breaking this cycle requires careful planning and often significant upfront investment in both technology and human capital.

b. Cybersecurity Vulnerabilities

Digital transformation significantly expands the attack surface for supply chains, introducing three emerging threat vectors:

(1) Third-party risks. 56% of breaches originate from vendor systems (Verizon, 2023), highlighting the vulnerabilities introduced by increasingly interconnected supply networks. As organizations digitize their supply chains and integrate with partner systems, they inadvertently expose themselves to security weaknesses in their vendors' infrastructure.

(2) IOT device vulnerabilities. The average manufacturing facility has 35,000 unprotected IoT endpoints (Palo Alto Networks, 2023), providing numerous entry points for malicious actors. Many IoT devices were designed with functionality rather than security in mind, making them easy targets for exploitation.

(3) AI model poisoning. Adversarial attacks on machine learning systems increased 245% in 2022 (MITRE, 2023), as bad actors learn to manipulate training data and algorithms. These attacks can cause AI systems to make incorrect predictions or decisions, potentially disrupting entire supply chains.

These security challenges are compounded by the fact that many organizations lack the specialized cybersecurity expertise needed to properly secure their digital supply chains. The cybersecurity skills gap continues to widen, with an estimated 3.5 million unfilled positions globally (ISC2, 2023), making it difficult for organizations to build and maintain robust security postures.

5. Organizational Barriers

a. Cultural Resistance

Human factors constitute the most persistent challenge to digital transformation, manifesting through several key phenomena:

(1) Change fatigue. Employees in transforming organizations experience an average of 10 major organizational changes annually (Prosci, 2023), leading to initiative exhaustion and resistance to new technologies. This fatigue is particularly acute in supply chain functions, which often face simultaneous pressures to adopt new technologies while maintaining day-to-day operations.

(2) Skill gaps. 73% of supply chain professionals lack competencies in data analytics (APICS, 2023), creating significant barriers to effective technology utilization. Many employees trained in traditional supply chain methods struggle to adapt to data-driven decision-making processes, requiring extensive retraining and upskilling initiatives.

(3) Leadership misalignment. Only 38% of digital transformations have full C-suite support (BCG, 2022), often resulting in conflicting priorities and resource allocation challenges. Without strong, unified leadership commitment, transformation initiatives frequently stall or fail to achieve their potential impact.

These cultural challenges are often more difficult to overcome than technical ones, as they require fundamental changes in mindset and behavior across entire organizations. Successful transformations typically involve comprehensive change management programs that address both the rational and emotional aspects of organizational change.

b. Process Inertia

Existing workflows often resist digital adaptation due to three key factors:

(1) Path dependency. Organizations tend to cling to familiar processes despite their inefficiencies, creating resistance to new ways of working. This inertia is particularly strong in long-established companies with deeply embedded operational routines.

(2) Measurement systems. Key performance indicators (KPIs) designed for analog operations often discourage digital behaviors. For example, metrics focused solely on cost reduction may undermine investments in long-term digital capabilities.

(3) Structural rigidity. Functional silos between departments impede the cross-functional collaboration needed for successful digital transformation. Many organizations struggle to break down these barriers and create truly integrated digital workflows.

Overcoming process inertia requires careful redesign of both formal systems (organizational structures, performance metrics) and informal norms (work habits, communication patterns). The most successful transformations align new digital processes with clear business value propositions that motivate employees to adopt new ways of working.

6. Financial and Environmental Constraints

a. Budgetary Limitations

Digital transformation requires substantial investment with delayed returns, presenting three key financial challenges:

(1) Cost structure. Initial implementation costs average $15-25 million for mid-sized firms (Accenture, 2023), including technology acquisition, system integration, and workforce training expenses. These costs can be prohibitive for organizations with limited capital reserves or competing investment priorities.

(2) ROI uncertainty. 58% of projects fail to deliver expected financial benefits (Bain, 2023), making it difficult to justify the required investments. The long-term nature of many digital transformation benefits further complicates ROI calculations, particularly in organizations with short-term performance pressures.

(3) Funding models. Traditional capital budgeting processes favor short-term, tangible investments over the long-term, intangible benefits of digital transformation. This mismatch often leads to underinvestment in critical digital capabilities.

These financial constraints are particularly acute in asset-intensive industries like manufacturing and logistics, where capital is often tied up in physical infrastructure. Creative financing approaches, such as as-a-service models or public-private partnerships, can help overcome these barriers but require organizations to rethink traditional investment paradigms.

b. External Pressures

Macroeconomic factors create additional hurdles to successful digital transformation:

(1) **Regulatory complexity**. Data privacy laws (GDPR, CCPA) and industry-specific regulations increase compliance costs and implementation complexity. Navigating these requirements while pursuing digital innovation requires significant legal and technical expertise.

(2) **Geopolitical instability**. Trade wars and export controls disrupt technology supply chains, making it difficult to source critical digital transformation components. Recent chip shortages, for example, have delayed many organizations' IoT deployment timelines.

(3) **Talent shortages**. The global SCM talent gap will reach 6.2 million by 2025 (DHL, 2023), particularly in specialized areas like data science and cybersecurity. This shortage makes it increasingly difficult to staff transformation initiatives with qualified personnel.

These external factors often lie beyond any single organization's control, requiring adaptive strategies that can accommodate unpredictable environmental changes. The most resilient organizations build flexibility into their transformation roadmaps, allowing them to adjust course as external conditions evolve.

7. Case Studies of Successful Transformation

a. Schneider Electric's Digital Twin Implementation

The energy management company achieved remarkable results through its digital transformation initiative:

(1) 20% reduction in planning cycles through real-time simulation and optimization.

(2) 15% improvement in on-time deliveries via enhanced visibility and coordination.

(3) $100 million annual savings from reduced inventory and improved asset utilization.

Key success factors included:

(1) **Phased rollout**. Beginning with pilot projects in select facilities before scaling globally.

(2) **Change management**. Extensive training programs and clear communication of benefits.

(3) **Executive sponsorship**. Strong CEO-level support for the transformation vision.

Schneider's experience demonstrates how a well-planned, comprehensively supported digital transformation can deliver substantial operational and financial benefits (Schneider Electric, 2022).

b. Walmart's Blockchain Adoption

The retail giant's food traceability system achieved breakthrough performance improvements:

(1) Reduced verification time from 7 days to 2.2 seconds through automated data sharing.

(2) Cut food waste by 30% through improved inventory management and recall precision.

(3) Improved recall accuracy by 98% by enabling precise tracking of contaminated items.

Critical lessons from Walmart's experience include:

(1) **Start small**. Initial focus on high-value, low-complexity use cases (leafy greens).

(2) **Build ecosystems**. Collaboration with suppliers was essential for system success.

(3) **Demonstrate value**. Clear ROI metrics helped maintain stakeholder buy-in.

Walmart's blockchain implementation shows how targeted digital innovation can solve specific supply chain challenges while building capabilities for broader transformation (Walmart, 2021).

8. Recommendations and Implementation Framework

a. Strategic Approach

A four-phase implementation model provides structure for successful digital transformation:

(1) **Assessment (3-6 months)**. Conduct comprehensive digital maturity audit across people, processes, and technologies. Identify quick wins and long-term priorities.

(2) **Foundation (6-12 months)**. Upgrade core systems and infrastructure. Develop data governance frameworks and initial analytics capabilities.

(3) **Transformation (12-24 months)**. Deploy advanced technologies and redesign key processes. Implement change management programs.

(4) **Optimization (ongoing)**. Continuously improve systems and capabilities. Scale successful pilots across the organization.

This phased approach balances urgency with sustainability, allowing organizations to demonstrate early wins while building toward comprehensive transformation.

b. Practical Solutions

Specific recommendations for overcoming common challenges include:

(1) **Technology**. Adopt modular, API-first architectures that enable incremental modernization without requiring complete system replacements.

(2) **Organization**. Create dedicated digital enablement teams to bridge the gap between IT and business functions.

(3) **Finance**. Implement value-based funding models that account for both tangible and intangible transformation benefits.

(4) **Environment**. Develop strategic technology partnerships to mitigate talent shortages and share implementation risks.

These solutions address the multidimensional nature of digital transformation challenges, providing both immediate remedies and long-term capability building.

Conclusion

Digital SCM transformation represents a complex, multidimensional challenge requiring holistic solutions. While technological barriers are significant, the human and organizational dimensions prove most determinative of success. Organizations must view transformation not as a technology project but as a fundamental reinvention of operating models and mindsets. Those that successfully navigate these challenges will gain sustainable competitive advantage in an increasingly digital business landscape.

The case studies of Schneider Electric and Walmart demonstrate that successful transformation is possible, but requires careful planning, strong leadership, and sustained commitment. As digital technologies continue to evolve, organizations must build adaptive capabilities that allow them to continuously innovate and improve their supply chain operations.

Future research should explore the long-term sustainability of digital transformation benefits and the evolving skill requirements for supply chain professionals in increasingly digital work environments. Additionally, more work is needed to understand how small and medium enterprises can overcome the unique challenges they face in digital transformation.

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ARTIFICIAL INTELLIGENCE APPROACHES IN TRAFFIC CONTROLLING PLATFORMS RELATED TO LOGISTICS ENGINEERING: A COMPREHENSIVE SYSTEMATIC LITERATURE REVIEW

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Abstract

In the past decade, transportation intelligence has experienced remarkable progress in logistic engineering. This has led to extensive research studies in the traffic control domain. With the integration of Artificial Intelligence and the Internet of Things, numerous techniques have been developed that effectively tackle the challenges of traffic control. The integration of Artificial Intelligence in logistic engineering has revolutionized the concept of Smart Transportation. To ensure successful implementation, it is crucial to align with urban planning concepts. Neglecting this alignment could potentially result in conflicts while merging two frameworks, which could lead to various challenges. Therefore, it is imperative to prioritize a well-planned strategy that takes into account both Artificial Intelligence and urban planning principles for seamless integration in logistic engineering. This study explored how Artificial Intelligence has been utilized to manage traffic differently and evaluate its effectiveness in reducing congestion. 46 scholarly articles have been selected for the review. This study aims to tackle one of the biggest challenges faced by urban areas - traffic congestion. Through the use of cutting-edge Artificial Intelligence techniques like deep learning, reinforcement learning, computer vision, and Internet-of-Things, this study explores the applications that will have a positive impact on people's daily lives. To improve the process of communication, such as the incorporation of fifth-generation/sixth-generation (5G/6G) will have a positive impact on real-time monitoring. The integration of Artificial Intelligence is poised to revolutionize vehicular communication, leading to an effective transportation system with reduced traffic congestion related to logistic engineering.

Keywords: Automotive technology, congestion reduction, intelligence transportation system, logistic engineering, smart city, smart traffic management, vehicular communication

Introduction

When contemplating traffic control, it is crucial that traffic control is becoming a big impact day by day as a result of globalization related to logistic engineering. Because the smart city concept is gradually becoming a reality through globalization (Přibyl and Přibyl, 2015). As a result, fulfilling the smart city concept required good traffic flow control, vehicle management, and road safety management. It is critical to deal with traffic congestion while examining traffic flow management (Mehta, Mapp, and Gandhi, 2022). Because traffic jams are a time-consuming issue for millions of people. Therefore, traffic flow optimization must be a significant fact these days (Cikhardtová et al., 2016) in logistic engineering.

Consequently, most studies are attempting to determine how to satisfy future needs using emerging technologies. At that time, Artificial Intelligence (AI) moves into the contest. AI is playing a vital part in a wide range of industries, including health care, education, and engineering. Precisely, AI has tremendous potential for dealing with various situations in many domains. Regarding traffic control, several ways could be utilized to deal with traffic flow control (Hassan et al., 2022) related to logistic engineering. Machine learning, deep learning, computer vision, and other AI approaches have a variety of applications in traffic flow management.

This thorough literature review investigated the use of AI to address the issue of traffic control. Furthermore, this research looked at current trends and how AI has been employed to fill gaps and perform these effectively. In addition, future scholars will gain a brief understanding of how AI has evolved all over the years. Then scholars can identify the research gaps that need to be filled through their studies.

When analyzing prior endeavors, the team observed that multiple approaches have been devised to meet the needs of traffic control. Through the advancement of sensor technologies, traffic control, and management has evolved to adaptive traffic signal control related to logistic engineering. Because previous traffic lights utilized fixed times for regulating traffic flow at intersections. Following that, the notion of Intelligence Transportation Systems (ITS) arose (Misbahuddin et al., 2015). Various approaches have evolved under that concept, such as Smart Traffic Lights, Smart Mobility, Autonomous Vehicles, traffic flow predictions, and so on in logistic engineering.

AI applications deal with traffic control by employing techniques such as classification, prediction, detection, and so on. The detecting part has recently emerged impressively (Xu et al., 2021). As a result, the majority of research focuses on how to use the Object detection component to achieve the purpose of the traffic-controlling domain. When applied to real-world circumstances (Diwan, Anirudh, and Tembhurne, 2023), all of the abovementioned AI approaches have significant limitations. This literature review assists in effectively identifying those trends, limitations, and obstacles.

Research Questions

This research study provides answers to the following research questions (RQs).

1. RQ1: What is the compatibility of AI and intelligence transportation systems?

2. RQ2: How AI has been involved in traffic control?

3. RQ3: What are the limitations of AI in traffic control?

4. RQ4: What are the challenges of AI in traffic control?

Methodology

The literature review has been carried out with a highly methodical approach. The eight steps have been included to conduct this study by referring (Kithulwatta et al., 2022), (Kithulwatta et al., 2021), (Kithulwatta et al., 2021), (Kithulwatta et al., 2022), (Meerapperumage, Kithulwatta, and Rathnayaka, 2022), and (Jayaweera, Kithulwatta, and Rathnayaka, 2023). Every stage is outlined completely in Table 1. The step number is shown in column one. The second column gives the step name, while the last column describes the specific step.

Step Number	Step Name	Description
1	Need of the review	Determine the need for this literature study and outline it in the research description.
2	Identify Research Questions	To carry out the literature survey in a methodical manner.
3	Create search string	This aids in choosing literature.
4	Select primary literature	By deploying a search string to browse scientific databases for literature.
5	Inclusion / Exclusion	Comply with the standards for inclusion and exclusion to eliminate papers with specific filtering.
6	Quality Assurance	To conclude the literature chosen for this review, select the most relevant papers by reading the title, abstract, and conclusion of each study.
7	Synthesizing	Analyzing and bringing together knowledge from multiple sources to create a thorough understanding of the context.
8	Reporting	Understanding and exploring selected studies to write down the final observations, outcomes, and conclusion.

Table 1: Research Methodology Steps
Source: Author

Search String

1. **String 01**. “Artificial Intelligence” AND “Traffic Control” AND “Intelligence Transportation System”.

2. **String 02**. “Artificial Intelligence” AND “Traffic Control” AND “Intelligence Transportation System” AND “5G”.

3. **String 03**. “Object Detection” AND “Traffic Control” AND “YOLO”.

The aforementioned search strings were used to browse through several scientific databases. Recently, a combination of AI and intelligence transportation systems has emerged. As a consequence, the selected literature reviews were released from 2018 to 2023. It is also necessary that an open-access filter be used for finding relevant literature. Table 2 shows how the search string influences the results in various databases in the initial stage.

Scientific database	**Number of results**
IEEE Explore (https://ieeexplore.ieee.org)	22
MDPI (https://www.mdpi.com/)	3
Taylor & Francis (https://www.tandfonline.com)	5
Springer (https://link.springer.com)	2
Elsevier (https://beta.elsevier.com/)	11
Institutional Repository	3
Total	**46**

Table 2: Search string browsing summary
Source: Author

The bar chart in Figure 1 presents the distribution of publication years for the finalized research papers for the review study. There was a trend in the recent decades in the YOLO-based research activities on traffic control.

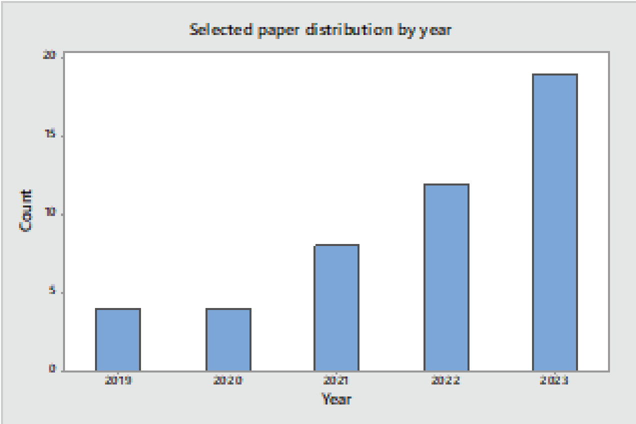

Figure 1: Distribution of papers by year
Source: Author

Artificial Intelligence and Intelligence Transportation Systems

1. Intelligence Transportation System

When examining intelligent Transportation Systems (ITS), pertains to the successful blend of many applications that enhance the existing transportation system. It has a wide range of possibilities for cover. Vehicular communication is a vital concept in smart transportation to support logistic engineering. It is divided into four categories: V2V, V2N, V2I, and V2P (Oladimeji et al., 2023). The vehicle to everything communication protocol is depicted in Figure 2.

The second concept is smart transportation IOT enablement. It consists of intelligent sensors, processing units, surveillance footage, and communication equipment that collects data and information from different situations. Because IoT-based transportation has advanced in several ways, such as advanced parking technology, intelligent traffic, and smart mobility in logistic engineering. These developments facilitate driving easier for drivers by providing effective navigation ideas, readily available parking slots, avoiding accidents, and self-driving vehicles using sensors. Because IoT-based smart transportation is expected to maintain road and pedestrian safety, provide adaptable and effective transportation for passengers, and eliminate time wasting (Chen et al., 2022).

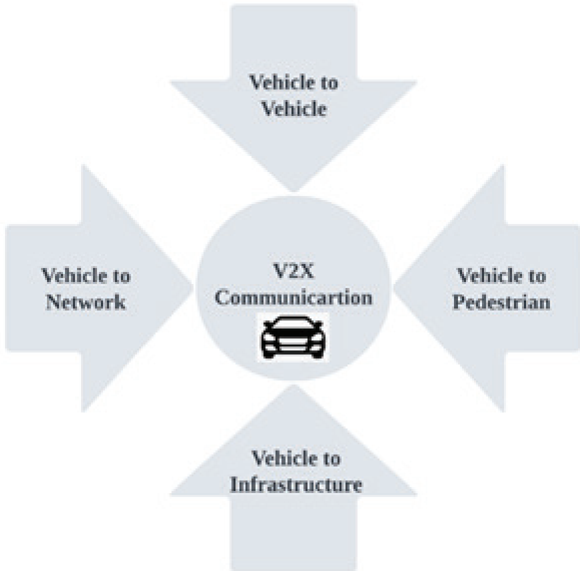

Figure 2: Vehicle to Everything (V2X) communication protocol (Chen et al., 2022)
Source: Author

In order to improve the safety and reliability of communication in Vehicular Ad hoc Networks (VANETs), the research proposes an AI-based Sugeno fuzzy-inference algorithm dubbed AI-TASFIS. The system's goal is to deliver safe trust-based clustering solutions that are less sophisticated, have shorter communication latency, less overhead expenses, and are superior in precisely locating trustworthy nodes for communication. The study's simulation outcomes showed that the AI-TASFIS system enhances network security, decreases end-to-end delay, and maximizes the ratio of packet deliveries and throughput. Furthermore, the research attempted to demonstrate the application of an Adaptive Neuro-Fuzzy Inference System (ANFIS) in the selection of trustworthy cluster leaders and cluster members (Gayathri and Gomathy, 2022).

V2V communication is a crucial aspect to consider, particularly when it comes to Unmanned Aerial Vehicles (UAVs). These vehicles need to communicate with each other to achieve specific goals, and China has already successfully incorporated them into emergency rescue operations. This success is due to the UAVs' flexibility, intelligence, and operational safety. The study highlighted the need to further analyze the use of UAVs in emergency rescue and identify areas for future development, such as technical innovation, building professional teams, and the combined use of manned aircraft and UAVs. The study also emphasized the importance of evaluating the use of UAVs in emergency rescue and recommends the integrated use of manned aircraft and UAVs to improve China's overall emergency response system (Li and Hu, 2021).

2. AI Involvement in Traffic Controlling

a. General AI Techniques. Regarding the AI techniques used for traffic control, the review (Abduljabbar et al., 2019) addresses numerous AI principles that can be applied to traffic control. Artificial Neural Networks (ANN), Genetic Algorithms (GA), Ant Colony Optimizer (ANO), Bee Colony Optimizer (BCO), Fuzzy Logic Model (FLM), and other algorithms are included. Additionally, it discusses the significance of knowledge-based systems and AI integration. They are primarily attempting to improve road safety, traffic management, public transportation, and urban mobility which are important to logistic engineering. Finally, the authors of the paper (Abduljabbar et al., 2019) concluded that AI may be utilized to handle the various issues of the specific area by lowering CO2 emissions, improving safety concerns, and lowering fuel usage.

The works in (Meerapperumage, Kithulwatta, and Rathnayaka, 2022) mostly target preventing accidents with the aid of machine learning methods and AI. Seeing as accidents are inextricably linked with traffic congestion, it is critical to take care of the facts that are inextricably linked with traffic management and AI. Chuan-Hsian et al. developed a highway surveillance framework for monitoring the highway using a deep-learning ANN. They employed deep learning algorithms in surveillance systems because deep learning algorithms can extract significant information from photos or videos and also provide greater accuracy and power in object recognition and classification. The suggested system can handle a variety of scenarios, including diverse lightning conditions and occlusions, which are typical on highways at all times (Chuan-Hsian and Sea, 2022). A specific study (Wang et al., 2023) has reviewed the urban air mobility-aided intelligent transportation system. It connects with AI via autonomous vehicles. Autonomous vehicles are an essential element in urban air mobility. As a result, those authors have focused on urban air mobility and ITS. What technological characteristics of urban air mobility exist? The work (Olayode et al., 2023) investigated how long and short trucks can contribute to traffic congestion. Authors (Olayode et al., 2023) used a hybrid ANN to develop an advanced traffic flow model for this purpose. In their study, this hybrid strategy yielded notable outcomes. They also employed a technique known as particle Swarm Optimization to fine-tune their generated model. Another significant work (Hassan et al., 2022) addressed the Deep Extreme Learning Machine (DELM) concept. It is capable of processing real-time data and making intelligent decisions at the right moment. DELM can also manage huge volumes of data and make rapid forecasts. As a result, the authors proposed a system for linked road intersections. The authors specifically said that this approach is best suited for larger urban areas with several road connections.

b. Smart Traffic Lights. When it comes to the principles of smart traffic light systems, it is noteworthy that various studies have been conducted in order to develop and improve smart traffic lights. The research [(Kumari et al., 2023)] describes how to use real-time images of crossings to analyze the traffic density of each direction and improve them using image processing to reduce congestion and give a quicker departure from the specific intersection. In that situation, faster transit may result in less air pollution in a certain location. Reinforcement traffic light control is a deep-learning adaptive technique. In reinforcement learning methodologies, the system may extract information from the environment and then adapt to the specific environment by making intelligent decisions. The study (Siripatana, Nopchanasuphap, and Chuai-Aree, 2021) suggests a concept of reducing the waiting time at the intersection. It is going to reduce congestion by capturing all four ways at intersections through a camera analyzing the vehicle count using image processing and then measuring the queue distance of each way of intersection. After that, the system calculates the optimum time of the green light for each way of intersection.

The paper (Sutisna et al., 2022) has proposed a smart traffic light concept through Deep Q Network that is a combination result of reinforcement learning and neural network concepts. The paper has implemented their proposed system using the Simulation of Urban Mobility (SUMO) simulator. They have shown that the proposed method has improved the traffic queue length performance. The study (Bokade, Jin, and Amato, 2023) provides a large-scale multi-agent reinforcement learning and representational communication approach for traffic light control in urban areas to adapt to changing circumstances and learn from past experience to effectively control traffic lights. They have tested and demonstrated their framework in order to maintain the least amount of traffic congestion while maintaining contact with every single agent. Zhong et al. proposed a technology called Probabilistic Graph Neural Networks (PGNNs) for traffic signal supervision. It is designed to improve the flow of traffic and reduce congestion. The PGNN model uses probabilistic analysis to compensate for fluctuations and variations in traffic conditions, making it stable and adaptable to changing circumstances (Zhong, Xu, and Zhou, 2021). The study (Khan et al., 2022) attempts to use adaptive traffic signals to handle traffic congestion at intersections by merging machine learning and image processing techniques. For the traffic clearance part, they used the YOLOv3. Because they concluded that the YOLOv3 has correct mean average precision (mAP) and Interaction over union (IOU) values in object-detecting tasks. They achieved the highest level of object detection by detecting objects with an 80% accuracy rate.

Challenges and Limitations of AI Involvement in Traffic Controlling

Discovering reliable and consistent data was noted as a major challenge in the logistic engineering discipline. Because most of the time traffic data doesn't exist for a particular duration or a specific weather condition [(Cheong, Lim, and Parthiban, 2023)]. As a result, the most challenging part is to collect traffic statistics wisely through that specific region. Because no two regions' traffic flows are the same. Another issue is dealing with the complexity of traffic systems. Because the intersection locations offer difficult circumstances. As a result, the system's linkages of pedestrians, cars, traffic lights, and infrastructures must be managed. Therefore, AI models must handle the complexity and ambiguity of all circumstances. [(Ramana et al., 2023)]. When it pertains to adaptive signal controls, they collect data from IOT equipment and video surveillance systems. However, all of these infrastructures have limitations in various environmental conditions such as weather, location, special events, and so on. As a result, while building real-time monitoring systems, those constraints must also be addressed. (Wenjuan and Jianfeng, 2022).

When considering AI approaches for deployment, it is necessary to remember that the AI model must meet safety and security concerns by Ensuring that AI models produce trustworthy and safe decisions, especially in critical situations. Another significant fact is the lack of facilities and resources. Because considerable amounts of infrastructure may be required when we implement a system with AI integration. However, when they are used in the real world, they may have a significant impact on meeting the requirements. Because the costs of infrastructure are expensive. As a result, it will be a severe limitation. Other factors to consider while designing and deploying an AI system include real-time processing, integrating the new system with current systems, and regulatory and legal concerns. Finally, human trust and approval may enter the arena. These constraints and obstacles can arise during the development or deployment of the AI application.

Conclusions

Due to the contribution of AI, smart transportation systems are no longer a theoretical idea in logistic engineering in future decades. It is becoming more apparent by the day. This review provided a thorough description of both AI and Intelligent Transportation Systems. The descriptive analysis began with the response to RQ1. The main findings of the study then tackled RQ2 by reviewing many different studies and extracting a spirit of them. Finally, at the end of this study, RQ3 offered the solutions. AI contribution has the potential to have a significant impact on a variety of industries. The study has concluded how AI techniques can be used to improve traffic management when urban area planning. Because the adoption of technology is increasing every day. In addition, everyone is attempting to make everyday tasks easier. AI can be utilized to achieve those everyday needs more easily. The majority of the studies mentioned above have been developed and tested in real-world scenarios. By reading this review, it will be easy to gain a thorough understanding of how AI has been applied to traffic control and how those techniques can be improved further.

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IDENTIFYING CHALLENGES IN IMPLEMENTING AUTOMATION OF PICKING PROCESS IN FMCG WAREHOUSE

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Abstract

The implementation of warehouse automation is a vital consideration for organizations seeking to optimize productivity while reducing costs. A case study of two reputed organizations in the western province is considered in this investigation as part of a study on the challenge in the implementation of automation in the function of order-picking in Fast-Moving Consumer Goods (FMCG) warehouses in Sri Lanka. More specifically, by qualitatively analyzing, the study attempts to shed light on factors of organizational challenges, technical challenges, and people-related Challenges through theme and interview analysis. Results show operational disruptions and financial constraints, to be significant organizational barriers. Resistance and job security concerns represent key people-related concerns, with technical concerns in terms of system failures, integration issues, and accuracy in automation contributing to the challenge of change. Existing automation technology, including Warehouse Management Systems (WMS), Radio Frequency Identification (RFID), and voice-picking technology, is discussed in the study and its impact on productivity in a warehouse is analyzed. Firms have implemented these solutions to help address these problems, including the gradual implementation of automation, retraining of staff and business continuity plans. The study highlights that aligning automation initiatives with long-term business goals and engaging relevant stakeholders with excellent communication can be the key to driving acceptance and enabling smooth transition.

Keywords: Warehouse automation, order picking, fast moving consumer goods, organizational challenges, people challenges, technical challenges, mitigation strategies

Introduction

Supply chain management focuses on controlling the flow of goods, with warehouses being an essential component (Oey & Nofrimurti, 2018).. Warehousing stores goods between stages in the supply chain, allowing for quick response to changes in demand and reducing response time in unpredictable transportation networks (Bartholdi & Hackman, 2017). Warehouses connect all business operations, including purchasing, production, distribution, and planning, and can be cost-effective in lowering inefficiencies and improving reliability to meet client demands (Prasetyawan & Ibrahim, 2020).

There are several categories for different kinds of warehouses. Classified warehouses into, production warehouses, distribution centers, raw material warehouse, work-in-process warehouses, finished goods warehouses, distribution warehouses, fulfilment warehouses, value-added service warehouses (Oey & Nofrimurti, 2018).

This research examines two FMCG warehouses in Sri Lanka, Logicare Private Limited and John Keels Logistics distribution center. These warehouses serve as communication hubs and storage facilities for retailers and manufacturers. Order picking, a laborious and expensive process, is undergoing modifications to meet modern requirements (Muter & Öncan, 2022).

Research scope

1. Research problem

Order-picking is the most expensive warehousing activity, costing 65% of total operations. It's a time-consuming and labor-intensive process (Muter & Öncan, 2022). The research problem focuses on the challenges experienced by FMCG warehouses as they switch from manual order-picking processes to automated systems. The research aims to understand the specific challenges faced during this transition.

2. Research question

a. What are the existing automation methods using FMCG warehouses in the picking process?

b. What are the challenges FMCG warehouses face when implementing automation to their order picking process?

c. What are the solutions that they can implement to mitigate these challenges?

3. Research aim

The aim of this research is to determine and evaluate the difficulties warehouse firms face while automating labor-intensive order-picking procedures, and to provide possible solutions to get over these problems.

4. Research objectives

a. To identify existing automation technologies used in warehouse order picking operations.

b. To investigate the particular challenges through in-depth case studies in benchmark warehouse companies when implementing automation.

c. To create and suggest effective solutions for the issues that have been identified using information from the case studies and literature analysis.

Limitations

This research focuses on the challenges of implementing automation in the picking process within Fast-Moving Consumer Goods (FMCG) warehouse in western province, Sri Lanka, specifically at two Benchmarked warehouses. As a result, the findings may not apply to other warehouses or regions and other warehouse activities like receiving, putting, shipping. However, this paper investigates organizational challenges, technical challenges and people challenges only.

Literature Review

The global business environment has been changing rapidly and profoundly these past few decades. It has made the market more complicated forcing companies to be competitive day by day. The typical warehouse that a specific logistics firm has plays an important role in the entire supply chain process (Martins et al., 2020) .

The warehouse is a place where goods and cargo are kept, handled & delivered when requested by the user end. The warehouse's primary functions include risk bearing, financing, processing, grading/branding, shipping, and product storage and protection (Pandian, 2019). Warehouse operations involve receiving goods, coordinating unloading, storing, picking, packing, and shipping. (Indian Institute of Materials Management, 2020b).

The Fast-Moving Consumer Goods (FMCG) sector is a major factor of the global economy, which is defined by intense competition and rapidly shifting consumer preferences (Henry Ejiga Adama & Chukwuekem David Okeke, 2024). The products in FMCG sector includes household products food and beverages, personal care goods etc which have short shelf lives ("Balancing Demand and Supply: Inventory Allocation in FMCG," 2023).

Order picking is a costly warehouse operation that involves collecting products from storage locations to meet specific consumer needs. Manual picking, also known as pickby-order or picker-to-parts, is the most common method, requiring pickers to move across racks and spend 15% of their time picking items (Gajšek et al., 2020), (Souiden et al., 2020).

According to a report from Monteage Technologies, nearly 90% of warehouses worldwide are still either manual or barely automated (Kumar et al., 2021). In Sri Lanka most of the warehousing operations are manual and labor-intensive. It would be a major problem soon due to a labor shortage (Modeste Tse, 2023).

1. Existing Automation Systems in the Picking Process

a. Automated guided vehicles (AGVs)

Automated guided vehicles (AGVs) are utilized in various applications, including flexible manufacturing, automated warehouse systems, and container terminal systems, reducing costs by over 40% (Zhang et al., 2023) .

b. RFID

RFID is an automatic object identification method using radio transponders. RFID tags store data that RFID reader can read from a distance. The tag, chip, and antenna are essential components of a standard (Gradetsky et al., n.d.).

c. Warehouses Management System (WMS)

Warehouse Management System (WMS) is essential for monitoring warehouse activity. The Warehouse Management System can help to manage all of the activities happened within a warehouse, such activities include receiving, putaway, order processing/picking, outbound checking/loading and stock take/ stock opname (Amanda Istiqomah et al., 2020).

d. Voice picking

Pick-by-Voice is a hands-free information provision system where pickers use earphones to communicate order information, item placement, and pick quantity. They can also speak with the system to validate what they picked and where it has been placed (Heinin & Sohlberg, 2023).

Methodology

This research explores challenges and solutions in automation in FMCG warehouse environments using a case study approach. It is qualitative, focusing on individuals and their environment, and uses non-numeric data analysis. The study uses face-to-face interviews with a semi-structured approach, and applies thematic analysis to reveal patterns, explicate data, and form themes (Kiger & Varpio, 2020).

Thematic analysis involves six phases. There are familiarization with the data, generating initial codes, generating themes, examining possible themes, defining and naming themes, and producing a report (Byrne, 2022).

NVivo is the data analyzing software that is used in this research. NVivo is a CAQDAS software which assists researchers to collect data, organize data, analyze data, visualize data and report data (Dhakal, 2022).

Analysis

This analysis examines warehouse automation technologies and potential challenges, based on data from warehouse visits and interviews. It aims to identify technical, organizational, and people aspects of automation adoption. The analysis provides actionable recommendations for optimizing automation adoption and mitigating risks. Experts from Logicare Private Limited and John Keells Logistics contributed to the analysis.

1. Responder code and responder profile

a. **Responder 01 -** Senior executive at operations with 6 years of experience in FMCG industry.

b. **Responder 02** – Inventory manger with 6 years of experience in FMCG industry.

c. **Responder 03** – Head of operations with 17 years of experience in warehousing.

2. Data observations

From the interview responses, the following technologies are identified:

Warehouses have adopted various technologies to enhance efficiency. RFID is used to track inventory and automate picking, with some companies using it for over 12 years while others are just adopting it. Warehouse Management Systems (WMS) like SAP and Info WMS are widely used to manage inventory and fulfillment. Voice-picking technology offers hands-free operation via voice commands, though its implementation has faced challenges due to noise interference. Conveyor belts, commonly used in e-commerce, help reduce manual labor by moving goods through the warehouse, but they pose challenges for bulk storage environments.

3. Detailed data analysis

a. Analysis of key challenges

The warehouse company faces organizational, people, and technical challenges during automation in the picking process, with four main themes identified using thematic analysis and NVivo software.

b. Organizational challenges

As per the interview data warehouses commonly face barriers like operational disruptions, financial constraints, and regulatory compliance issues while Implementing automation in picking process.

(1) Operational Disruptions During Automation Implementation. "Moving to automation caused disruptions, but we mitigated impact by informing customers in advance" (Responder 01).

(2) Financial Considerations & ROI Assessment. "Before adopting automation, we conduct financial feasibility studies to determine affordability and ROI expectations. Management evaluates whether the investment aligns with company growth objectives before making a final decision" (Responder 03).

(3) Warehouse Scale and Complexity. "Our warehouse handles high order volumes, making automation essential but challenging" (Responder 03).

(4) Automation Integration Process. "When we transitioned from SAP to Info WMS, we reviewed many suppliers and considered various factors. The transition period took one and a half years, and our IT team closely collaborated with us" (Responder 01).

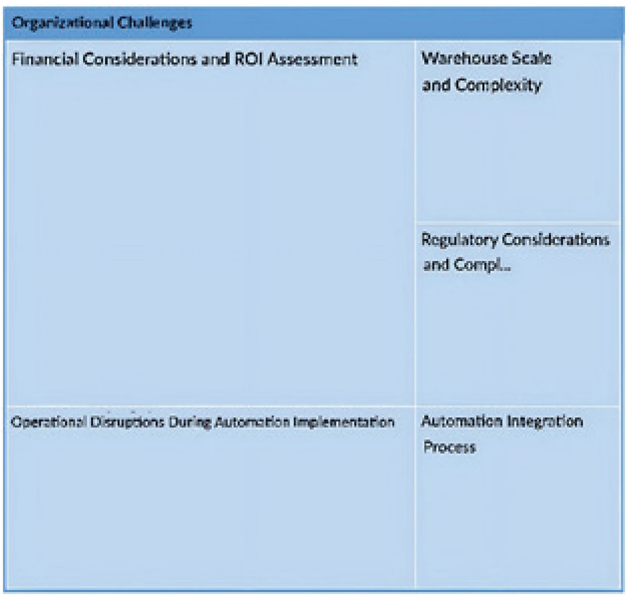

Figure 1: Organizational Challenges Hierarchy Chart of Codes
Source: Interview Data, 2024

(5) People challenges

As per the interview data, human factor is still one of the largest barriers to automation.

i. **Employee Resistance**. "Workers were reluctant to switch to automation because they were used to manual methods" (Responder 01 and 02).

ii. **Job Security Concerns Due to Automation**. Automation presents a significant threat to job security. During a previous assessment, we found that introducing conveyor belts could eliminate up to 80% of employees in specific tasks. Our company predominantly hires contract-based workers, meaning we are only ethically committed to their employment for the duration of their contracts (Responder 03).

Figure 2: People Challenges Hierarchy Chart of Codes
Source: Interview Data, 2024

(6) Technical challenges

As per the interview data, despite advancements in automation, warehouses still experience system failures, integration issues, and performance inconsistencies that hinder efficiency.

i. System Breakdowns & Failures“We faced breakdowns, network issues, and update failures that disrupted order picking” (Responder 01).

ii. Integration Issues “WMS and automation devices don’t connect directly; they require APIs, which complicate integration” (Response 03).

iii. Customization Challenges: “Customization of WMS was expensive and took longer than expected, with lingering system bugs” (Response 02).

iv. Noise Disruptions: “Human and vehicle noise interfered with voice recognition, making it hard to use voice-picking technology” (Response 03).

v. System Accuracy & Reliability: “WMS does not always function with full accuracy; signal and data traffic issues occur frequently” (Response 03).

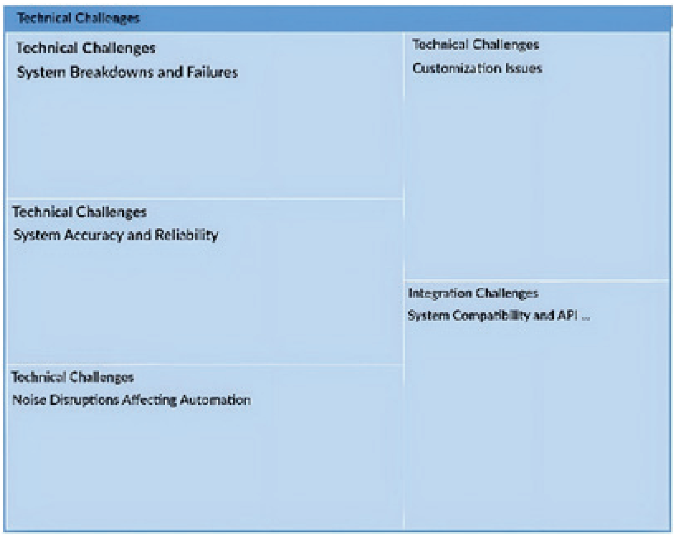

Figure 3: Technical Challenges Hierarchy Chart of Codes
Source: Interview Data, 2024

(7) Mitigation strategies

To address the challenges identified, warehouses have implemented various mitigation strategies, categorized into technical solutions, employee engagement, and strategic planning.

i. **Business Continuity Plan**. "We have a BCP plan. If an automation failure occurs, we switch to Excel and inform customers about potential disruptions. For large orders, we negotiate alternative solutions with clients" (Response 01 and 02).

ii. **Managing Employee Resistance using change management**. "We focused on change management, organizing multiple training programs to familiarize employees with the new technology. We appointed leaders to train others, provided them with special identification (T-shirts), and placed posters around the company to reinforce awareness" (Response 02).

iii. **Project Risk Assessments**. "Automation was introduced gradually to avoid operational disruptions" (Response 01).

iv. **Workforce Adjustments**. "New roles were created for employees to work alongside automation." (Response 01).

v. **Cybersecurity & Data Protection**. "Regular security audits help us ensure data safety" (Response 01).

vi. **Training & Upskilling Needs**. "Employees received training on new systems, ensuring they could adapt. Whenever automation is introduced, we conduct training programs. We identify key employees, provide training, and ensure smooth adaptation" (Response 03).

vii. **Addressing Technical Failures in Automation**. "Our dedicated IT team handles system maintenance. In case of major failures, we switch to manual order picking using Excel" (Responder 01).

viii. **Strategic Alignment of Automation with Business Goals**. "Setting long-term strategic goals is increasingly difficult due to rapid technological advancements. Every year, we reassess our objectives and determine which automation technologies to implement based on market trends and company priorities" (Responder 03).

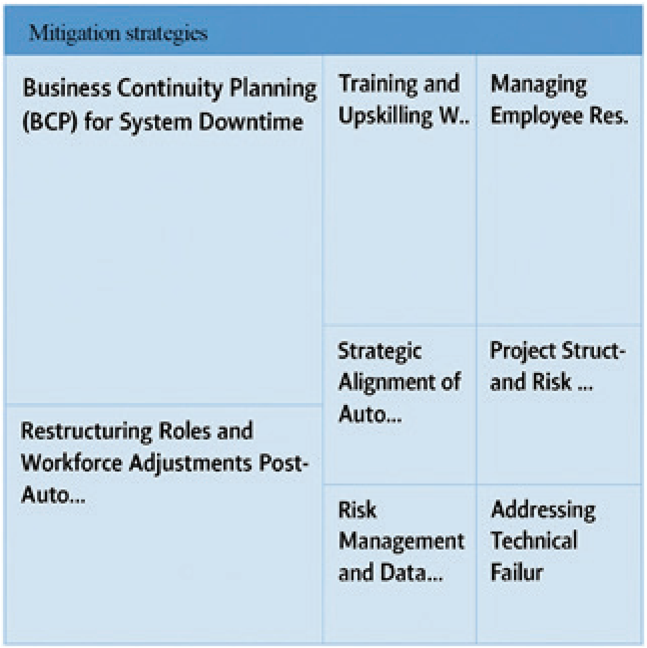

Figure 4: Mitigation Strategies Hierarchy Chart of Codes
Source: Interview Data, 2024

Discussion

The study explored the challenges faced by FMCG warehouses in Sri Lanka's Western Province when transitioning from manual to automated order-picking processes. The first research question examined existing automation methods, revealing technologies such as Automated Guided Vehicles (AGVs), Radio Frequency Identification (RFID), Warehouse Management Systems (WMS), and Voice Picking. While RFID is widely used, WMS adoption varies, with integration issues being a key concern. Voice picking remains uncommon due to noise disruptions, and conveyor belts are primarily used for small parcels.

The second research question focused on challenges in automation implementation, categorized into organizational, people, and technical issues. Organizational challenges include operational disruptions, financial constraints, regulatory compliance, and the need for flexible systems. People challenges involve employee resistance, job security concerns, and limited knowledge of AI and IoT. System breakdowns is the key challenge in technical aspect.

The third research question explored solutions to mitigate these challenges. Strategies include developing business continuity plans, adopting change management to address employee resistance, conducting project risk assessments, implementing workforce adjustments, strengthening cybersecurity, and investing in training and upskilling programs.

Future Research Directions

Further research should explore:

1. Quantitative assessment of employee training impact on automation efficiency in FMCG warehouses.

2. Evaluating the role of business continuity planning in sustaining automated warehouse operations.

3. The effect of predictive maintenance on reducing automation failures.

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AI-DRIVEN DIGITAL TWIN TECHNOLOGY FOR SMART MILITARY LOGISTICS: ENHANCING OPERATIONAL EFFICIENCY AND RESILIENCE

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Abstract

Artificial Intelligence (AI) driven Digital Twin Technology (DTT) presents a transformation in military logistics operations, creating a virtual replica of a physical object, process or system. This study explores the impact of DTT integration in operational efficiency and resilience improvement based on real-time monitoring, predictive analytics, and simulation abilities. The technological advancement facilitates in improving Inventory control route optimization, and better resource allocation while reducing operational costs by 20-30%. Notwithstanding the advantages the implementation of DTT has encounter significant challenges such as cybersecurity vulnerabilities, system interoperability, and complex data management. The Strategic recommendations include advanced technology integration, enhanced predictive analytics, sustainability focus, supply chain vulnerability mitigation, and continuous workforce training and development. This article concludes that AI-driven DTT can reform military logistics operations by creating smarter, more agile systems capable of addressing existing and emerging challenges in volatile environments.

Keywords: Artificial intelligence, digital twin technology, efficiency, resilience, technology

Introduction

Military logistics has been the foundation for operational success since the era of the first organised army in the world (Serrano, et al., 2023). The military supply chain operations gradually improved efficiency by integrating advanced technology (Tuli, 2023). However, the rising geopolitical conflict and volatile global economic conditions drive military logistics into a more vulnerable state that requires enhanced readiness and adaptability in building resilient supply chain operations by highlighting the necessity of transforming from traditional practices towards advanced solutions (Faria, et al., 2024). According to the studies, the conventional military supply chain encountered 30–40% more disruptions, risking operational failures compared to the commercial sector (Tuli, 2023).

Digital Twin Technology (DTT) creates a virtual replica of a physical object, process or system, integrating the Internet of Things (IoT), big data and Artificial

Intelligence (AI). It allows data collection, real-time monitoring, analysis, simulation and data-driven decision-making to improve operational efficiency and build resilient supply chain operations (Faria, et al., 2024; Vidyalakshmi, et al., 2025; McDonald & Ngo, 2024).

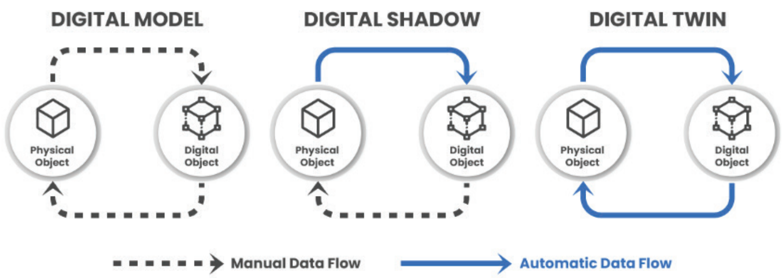

Figure 1: Three main modules of Digital Twin Technology
Source: Andrade, 2024

Integrating AI-driven DTT in military logistics creates a virtual model of assets and processes that enables a better understanding of logistics operations and resource optimisation. This technology ensures the preparedness and rapid identification of potential challenges (Tuli, 2023; Restack, 2025a) by simulating different situations. It enables military commanders to make data-driven decisions, thereby enhancing operational efficiency (Matyi & Tamás, 2021; Restack, 2025a). Further, AI-driven DTT fosters resilience in military logistics operations, allowing for quick adjustments in unstable environments (Tuli, 2023), while improving rapid response capabilities in unpredictable conditions (Matyi & Tamás, 2021; Restack, 2025a).

The AI-driven DTT directly impacts organisational operations by improving and optimising inventory management with real-time monitoring and predictive analytics, enabling effective prediction of supply requirements (Sodiya, et al., 2024).It further optimises transportation routes, ensuring on-time deliveries and cost reduction that facilitate constant supply chain efficiency (Devi, 2023). AI-driven DTT in warehouse operations leads to reduced operational costs through automation and better resource allocation (Sodiya, et al., 2024). Studies highlighted that AI-driven DTT increases operational efficiency by 20–30% while significantly reducing labour costs and enhancing productivity in the entire logistics process (Devi, 2023).

Despite its benefits, AI-driven DTT encounters challenges. One of the key challenges is cyber-attacks and maintaining sustainable cyber security operations. Integration of the existing system with new technology and achieving interoperability across various military branches are also key challenges. To reduce user resistance and ensure the effective usage of AI-driven DTT, well-structured training programmes are essential to develop the technical and strategic skills of military personnel (Faria, et al., 2024).

Considering the strategic importance and future outlook, DTT enhances agility in military logistics through real-time tracking and simulation, enabling quick adjustment according to the changes in the battlefield (Faria, et al., 2024). It improves resilience and readiness by having the mission-critical assets operational and reducing equipment downtime through predictive maintenance (Sani, et al., 2022a; Tuli, 2023; Faria, et al., 2024). DTT facilitates better decision-making and planning through scenario simulation and real-time data visibility (Restack, 2025c). DTT integration with AI and IoT enhances operational readiness and optimises logistics operations in volatile environments (Sani, et al., 2022a; Faria, et al., 2024).

Methodology & Approach

This research article applied desk research methodology, with a thorough examination of available literature on AI-driven DTT in logistics and its usage in the military logistics context. This approach includes methodical exploration of research papers, technical reports, scholarly articles and case studies, especially discussing the successful implementation of the U.S. Air Force's Model One initiative (Topolewski, et al., 2023).

This study further analysed facts from a qualitative point of view, such as interoperability challenges and cybersecurity concerns, while utilising the quantitative approach by highlighting the metrics of improvement of operational efficiency with the usage of this technology, which provides a balanced evaluation (Topolewski, et al., 2023).

The comprehensive analysis of the traditional military logistics practices and logistics operations after AI-driven DTT adoption explores the degree of performance differences. The methodological approach determined repeating models within different sources while confirming the reliability of the findings of the article and facilitating the provision of data-driven recommendations (Leˆ & Schmid, 2022).

Technological Foundations of AI-Driven Digital Twin Systems

DTT designs a virtual model of logistics procedures, facilitating an accurate prediction process and simulation that optimises the workflow. Leveraging real-time data analysis enhances decision-making empowerment, which improves logistics management efficiency (Matyi & Tamás, 2021). DTT integration with AI allows for predictive capabilities, enabling anticipatory disruption handling and resource allocation optimisation (Sander, 2024).In addition, DTT allows the creation of different scenarios that facilitate strategic and operational level commanders to identify the outcomes of strategies before implementation, mitigate risks and maintain a steady logistics process (Matyi & Tamás, 2021).

1. Definitions and Key Components of AI-Driven Digital Twin Technology

a. **Digital Twin Technology**. is an exact digital version of a physical asset, process or system, formulating by integrating real-time data and analytics to accurately reflects real time conditions, performance and behaviours of the actual physical edition (Kuo, et al., 2021; Xiao, et al., 2025; Vidyalakshmi, et al., 2025).

b. **Internet of Things (IoT)**. devices and sensors that aids in transmitting data of physical property into their digital twins, to ensure that the play a crucial role in feeding data from physical assets into their digital twins, ensuring that the digital version is conversant with real-world conditions (Terler, 2023).

c. **Cloud Computing Services**. facilitates DTT by storing and processing capabilities for provide the necessary storage and computational power for retrieving and scaling Digital Twin applications in different geographical areas by enabling seamless integration and collaboration (Matyi & Tamás, 2021).

d. **Artificial Intelligence (AI)**. improves the ability of DTT by allowing predict and analyse problems, simulations and prepare for different conditions. This will facilitate organizations to prepare in advance and enhance performance (Andrade, 2024).

The integration of these technologies empowering real-time tracking and system optimization for achieving efficiency and inventions in different industries.

2. Military logistics application

In the current context, AI-driven DTT is widely utilised to enhance the resilience and efficiency of military logistics. This technology primarily facilitates the rapid identification of challenges, using proactive measures for dispute mitigation (Tuli, 2023). Various situation simulations improve the management of logistics operations, resource optimisation and cost reduction (Restack, 2025c). Integration of AI-based analysing capabilities fosters enhanced data-driven decision-making and provides practical insights that facilitate providing quick, data-driven strategic solutions (Sander, 2024).

a. Real time tracking and inventory management

AI-driven DTT enables military organisations to track shipments in real-time, facilitating identifying delays, implementing alternatives and reducing transit periods to improve responsiveness and efficiency (Faria, et al., 2024). This technology facilitates proactive inventory management by providing precise perceptions of inventory levels, demand forecasting and avoiding overstocking or stockouts (Restack, 2025c). Through AI-supported analysis, improve decision-making capabilities and adaptability for volatile environments and enhance resource management that ultimately ensures operational readiness to meet national objectives (Faria, et al., 2024).

b. Predictive risk analysis and risk management

DTT in military logistics helps identify vulnerabilities and analyse risks and their possible effect on mission success. Situation simulations allow operational commands to visualise and analyse potential failures and plan and implement mitigation strategies based on degrees of threats (Faria, et al., 2024). The technology also facilitates rapid and more efficient response while developing preparedness for unpredictable situations (Restack, 2025a). As a whole, this technology improves the operational strength of military logistics to adopt and sustain logistics strategies effectively (Faria, et al., 2024).

c. Resource allocation and route optimization

AI-driven DTT allows military logisticians to allocate and distribute resources effectively through real-time data analysis on the demand for such items. DTT facilitates decision-making by providing insights on vehicle performance, weather and real-time traffic updates to ensure on-time, efficient deliveries that lead to better transport decisions, resource optimisation, cost reduction and sustainable practices in logistics operations (Faria, et al., 2024). Integrating real-time data analysis improves the efficiency of military operations and quick adaptability to growing battlefield conditions (Restack, 2025c).

d. Addressing challengers in military logistics

Despite benefits, challenges are also identified in implementing AI-driven DTT in military logistics. One of the key challenges is cybersecurity, as the high usage rate of digital platforms and technologies leveraged a possible threat of cyberattacks, creating a critical and difficult situation in data security (Sani, et al., 2022a). Interoperability is another challenge when collaboratively operating with different logistics departments and other amalgamated systems, which hinders the resource allocation and planning of supply routes in decentralised command and operation scenarios (Restack, 2025c). The complexity of data management is another issue of concern (Sani, et al., 2022a).

e. Enhance training and development

A well-trained and skilled human resource able to handle complex systems like DTT in military logistics is a key success of these technologies. Thus, conducting theoretically designed specialised training on DTT is an urgent requirement (Tuli, 2023). Further, reducing such expenses and recruiting personnel with a sound background in these technologies is a better suggestion (Restack, 2025c). Retention of such a skilled workforce is another challenge which needs to apply effective retention strategies like continuous training programmes and career advancement to ensure employees have updated knowledge of these technologies (Tuli, 2023). Moreover, phasing up the innovation and adoption process and providing education and skill development are critical to ensure logistics teams are successfully adopting developing technologies (Sander, 2024).

f. Real time data synchronization

Ensuring constant synchronisation of physical assets, methods or processes and their digital twins is important to ensure the virtual processes replicate real-time scenarios, leveraging effective tracking and control. This real-time information facilitates data-driven decision-making by presenting updated tactical perceptions, which results in improved responsiveness. This real-time data synchronisation allows proactive involvement, allowing logistics commanders to detect and resolve disputes in advance by improving efficiency and minimising outages (Roumeliotis, et al., 2024).

Case Studies

1. Implementation of AI- Enabled Digital Twins

According to the studies, several military organisations have integrated AI-driven digital twin technology to improve their logistics functions, considering its positive impact (Faria, et al., 2024). Among those organisations, the U.S. Air Force's Model One initiative is mainly concerned with connecting different data sources with the use of digital threading while ensuring protection (Restack, 2025c). This initiative facilitates a continuous flow of data directing operational efficiency improvement and decision-making on logistics operations (Tuli, 2023). As per the outcomes of the studies, the pioneers who adopted this technology have experienced significant positive results, such as a 20%–30% improvement in operational efficiency and a 40% labour cost reduction within just 90 days of a period after the initial integration (Writer, 2024). These results have proven the capacity of AI-driven DTT in restructuring operations and reflect optimum resource utilisation in military logistics settings (Faria, et al., 2024).

2. Predictive Maintenance in Military Equipment

The AI-driven DTT facilitates military logistics to exercise per directive maintenance effectively, resulting in better management of assets and operational planning processes (Writer, 2024). This practice will mitigate the risk of unforeseen breakdowns (Tuli, 2023). Further applying proactive strategies reduces equipment downtime and results in keeping mission-critical assets at an operational level as and when required (Writer, 2024). Moreover, adopting these good practices incorporated with technology supports the expansion of the equipment life cycle while facilitating long-term cost savings and better resource utilisation (Tuli, 2023).

3. Streamlining Supply Chain Management

DTT is progressively utilised by military logistics to modernise the supply chain management, which significantly contributes to improving operational efficiency (Ott, 2025). Using the benefit of stimulation, visualising different supply chain situations facilitates military commanders to identify the blockages in advance and provide solutions for such challenges on time (Sani, et al., 2022a). The stimulation process further contributes to better resource allocation and delivery of supplies effectively (Anderson, 2025). The statistics extracted from the studies have proven that DTT has contributed 20 % to 50% to improving on-time deliveries in full quantity, showcasing its direct impact on logistics performance improvement (Sander, 2024). Adaptation of this technology increases the agility and responsiveness of the military logistics process and enhances the overall effectiveness and mission readiness (Sani, et al., 2022b)(Sani, Schaefer and Milisavljevic-Syed, 2022)

4. Continuous Improvement and Safety Training in Military Logistics

The iterative nature of DTT facilitates constant development in military operations through response integration and real-time data (Cerexio, 2023). Training in DTT provides a virtual mode stimulation of the exact physical experience while ensnaring the safety of logistics staff in learning and practice (Restack, 2025b). This system training allows employees to prepare themselves to encounter complex mission scenarios without exposing them to real-world dangers (Tuli, 2023). Apart from the training, DTT supports improving the effectiveness and efficiency of the logistics operations while reducing costs (Restack, 2025b).

Discussion & Analysis

1. Benefits of AI-Driven Digital Twin Technology in Military Logistics

a. Cost Reduction

As the studies prove, the AI-driven digital twin technology has contributed to reducing the operational costs of the organisations through its functionality by up to 30 % in some of the sectors. In a military context the cost reduction is much more important, especially in financial constraint situations. However, the adoption of DTT helps to streamline the process and facilitate better resource allocation (Restack, 2025c).

b. Improved Operational Efficiency

Through real-time data analysis, the DTT facilitates streamlining and optimising the process and workflows. The capability of DTT to simulate different occasions allows organisations to identify the inefficiencies and improve the overall logistics operations. Similarly, this technology facilitates providing real-time data for better decision-making and operational process optimisation (Terler, 2023).

c. Enhanced Predictive Capabilities

The AI integrated with digital twins enables organisations to forecast requirements in logistics operation processes and identify the possible destruction associated with real-time data analysis. However, this capability critically contributes to sustainable mission readiness and on-time supply deliveries to the battlefields (Restack, 2025a).

d. Increased Safety and Risk Management

DTT stimulates operations in digital platforms by allowing logistics personnel to identify and mitigate possible threats and risks prior to affecting men, machines or material. This capability facilitates creating and maintaining a safe working environment even in a highly risky military context (Restack, 2025b).

e. Adaptability to rapid response for volatile environment

The integration of DTT facilitates military logistics for quick adaptation to changing and complex requirements, such as catering to higher customer expectations and rapid order fulfilment. This flexibility facilitates handling the challenges in unpredictable and fast-changing environments, resetting inventory levels, rerouting supplies, and rapidly responding to new threats by ensuring a continuous flow of operations (Xpedel, 2025).

2. Critical challengers for implementing AI-Driven Digital Twin Technology in Military Logistics

a. High-cost involvement in Logistics infrastructure

Integration of AI-driven DTT in logistics operations needs to develop infrastructure facilities at the implementation stage and subsequent maintenance and upgrades, which create key challenges for military logistics, especially due to financial constraints. This limitation of fund allocation drives military commanders to make hard selections, especially in resource allocation that needs optimum cost efficiency together with redundancy and resilience maintenance in supply chain operations. (Sobb & Turnbull, 2020).

b. Modern Warfare Complexity and Technology Integration

The magnitude of the complexity of modern warfare increases with the rapid involvement of technology as well as the geographical factors, which require redesigning the logistics strategies accordingly. The present-day military operations are multi-domain, which need better coordination, flexibility and organisation for sudden interruption to maintain sustainable logistics operations and stay strong and resilient (Sani, et al., 2022a).

c. Data Management and Cybersecurity Challenges

The digital platform integration in military operations encounters challenges in controlling considerable amounts of data. This process required a better process in data gathering, transforming, storing and retrieving data through different systems. These interconnected systems create cybersecurity risks, highlighting the importance of protecting the sensitive information without being exposed to unauthorised parties (Sobb & Turnbull, 2020).

d. Technical Implementation barriers

Implementing advance technology like DTT and AI in military logistics encounter technical obstructions like incompatibilities in systems and complexity in data management. In order to overcome such issues military organizations must combine the operational framework which improve the performance, flexibility and efficiency in grooving logistics requirements (Sani, et al., 2022b).

3. Implications

a. Theoretical Implications

Therefore, this research intervenes in the theoretical background of military logistics through adopting DTT as an intelligent approach to update existing logistic models. It builds upon the existing knowledge on real-time data, analytics, and simulations as to how they contribute to making organizations more robust and flexible in logistics. The study provides empirical evidence for technology use in decision making in uncertain contexts of military conflicts and contributes to new theory development, which acknowledges technology integration in operational contexts of the defence sector. This supports the idea of technology in military strategic logistics management as well as the supply chain concepts of the future.

b. Practical Implications

The practical consideration demonstrates how capabilities identified by DTT affects military logistics operations through AI. Through ensuring enhanced accurate inventory, management of routes, and accurate planning of equipment maintenance, the technology cuts short the operational costs while increasing response time. It helps with planning ahead, monitoring the situation in the process, and decision-making under conditions that are more complicated than in the case of a linear process. The objectives of military organisations involved in the operations can attain better mission preparedness, optimised resource utilisation, as well as potential risks reduction. The study also recommends on-going training and investment in IT security and interoperability to support the effective utilisation and long-term success of this cutting-edge logistics system.

Conclusion and Recommendations

1. Conclusion

In conclusion, this study highlights the vital role of AI-driven Digital Twin Technology in improving the efficiency, adaptability, and resilience of military logistics operations. This technological advancement provides significant benefit such as improved monitoring, advanced analysis and data driven decision making is essential in volatile environment. To streamline the supply chain process better inventory management and proactive maintenance are important while training and development influence significantly in ensuring operational readiness (McDonald & Ngo, 2024).

The implementation of advance technology encounter challenges individually and commonly. To overcome challengers like cybersecurity issues and seamless collaboration needs skilful workforce. A carefully planned strategies are required to overcome the infrastructure, cost and complexity issues in integration while phased adoption facilitates smooth and sustainable system adoption.

However, as per the findings its understood that the AI-driven digital twin technologies have the capacity of redesign the military logistics operations smarter, more agile, and sustainable system that can effectively encounter existing and growing challengers in military logistics sector.

2. Recommendations

The conclusion of a comprehensive study suggests following strategic recommendations to maintain future readiness and sustainability of military logistics operations.

a. Integration of Advanced Technologies

The DTT required the incorporation of complementary technologies like AI, big data, automation and blockchain to improve the strength and adaptability of the system resulting to enhance real-time decision-making ability.

b. Improved Predictive Analytics

Predictive analysis lay foundation for predict and adopt measures for mitigation of disruptions utilizing smarter, data driven inputs useful for simulation and forecasting to optimize military logistics operations.

c. Concentrate on Sustainability

The minimising of waste, emission and carbon footprints are another key aspect that require to be pay more attention since digitalized logistics practises can significantly contributes to become environmentally responsible.

d. Addressing Supply Chain Vulnerabilities

Detecting, protecting and addressing the vulnerabilities in supply chain operations through better employment of DTT will enhance the strength of the supply chain operations against operational disruptions.

e. Training and Development

The continuous training and skill development is vital ensure the military logisticians are cable of hand and innovate growing technologies like DTT which result to develop internal capabilities required for long-term technology adaption.

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SUB THEME 02

RISK MANAGEMENT AND CRISIS RESPONSE: BUILDING RESILIENCE TO GLOBAL AND LOCAL MARKET FLUCTUATIONS

INTENTIONALLY KEPT BLANK

STRENGTHENING MALAYSIA'S DEFENCE SUPPLY CHAIN RESILIENCE IN NATIONAL DEFENCE INDUSTRY: A PATH TO SECURITY & ECONOMIC RESILIENCE

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Abstract

In an era marked by unprecedented global disruptions from pandemics to geopolitical strife, the resilience of supply chains has emerged as a cornerstone of national security and economic stability. For Malaysia's national defence industry, robust supply chain are not merely operational necessities but strategic imperatives, safeguarding the nation's sovereignty and economic vitality. The defence industry, inherently reliant on specialized technologies and timely access to critical resources, faces unique vulnerabilities exacerbated by global supply chain fragility. Recent challenges, including trade wars and regional instability, have underscored the risks of over-reliance on international suppliers and the urgent need for adaptive strategies. Malaysia's geopolitical position in Southeast Asia further amplifies these challenges, necessitating a supply chain framework that balances global integration with localized resilience. Disruptions in defence logistics not only jeopardize military readiness but also ripple through the economy, affecting industries reliant on defence contracts and innovation. Conversely, a resilient defence supply chain can catalyse economic growth by fostering local industries, creating jobs, and attracting foreign investment through demonstrated reliability. This paper explores strategies to fortify supply chain resilience within Malaysia's National Defence Industry (NDI), emphasizing its dual role in enhancing national security and driving economic resilience. From emphasizing localized production, technological innovation, strategic partnerships and investing in domestic manufacturing aim to mitigate risks while positioning Malaysia as a hub of innovation and stability. By strengthening domestic supply networks and leveraging resilient economic policies, Malaysia can mitigate external shocks while fostering self-sufficiency in critical defence capabilities. A resilient defence supply chain not only ensures national security but also contributes to economic stability, industrial growth, and technological advancement in the broader national ecosystem in an uncertain world.

Keywords: Defence supply chain resilience, national defence industry, self-reliance, economic resilience, defence economics

Introduction

In an era of global disruptions, supply chain resilience has become critical to national security and economic stability. Recent global events have highlighted the vulnerabilities of defence supply chains, disrupting military production and access to critical resources. The COVID-19 pandemic disrupted defence manufacturing globally, which delayed the U.S. F-35 program as well as India's fighter jet acquisitions, the US-China trade and tariff war caused semiconductor shortfalls impacting military technology production, and the Russia-Ukraine war caused defence material and energy shortages affecting the European and Russian defence industries. In response, Australia and other countries started shifting their focus to domestic defence manufacturing to mitigate dependence on foreign defence industries (Defence, 2006). These are some of the examples that Malaysia should learn from in order to strengthen the resilience of their defence supply chains and strategically bolster their defence capabilities to ensure national security alongside economic stability amidst volatile uncertainties in the global arena.

The Defence Supply Chain (DSC) is vital for the national security as it comprise of all organizations, resources and processes that are responsible for the defence supplies and services acquisition and provision within required time (Suhaimi, Zakiah Syamra, & Ahmad Rais Mohamad Mokhta, 2023). A resilient DSC is critical in protecting national interests and maintaining operational readiness at the highest levels as disruptions can compromise economic stability and military capabilities. The recent global crises and geopolitical tensions have also highlighted the gaps that stem from the dependency and over reliance on foreign suppliers, which stress the need for self-reliance within the adaptive defence supply chain (Suhaimi, Zakiah Syamra, & Ahmad Rais Mohamad Mokhta, 2023).

Malaysia's National Defence Industry (NDI) plays a strategic and important role in national security link to the economic development as it become a key enabler to achieve the National Defence Interests of 'prosperity' in pursuit of the National Defence Vision, underscore the interconnection between national defence and the economy, emphasizing the need of "protecting economic prosperity, development and growth opportunities, including interests abroad" (MINDEF, 2020). This undeniable nexus between defence and the economy underscores the necessity of a paradigm shift towards a resilient supply chain in the National Defence Industry (NDI) (refer Figure 1). The interconnection between defence and the civilian economy is evident in industries such as aerospace, shipbuilding, and automotive manufacturing, where technological advancements contribute to economic growth, job creation, and innovation. Strengthening Malaysia's defence industrial base not only enhances military self-sufficiency but also facilitates a broader socioeconomic development that include commercialization of defence technologies for civilian applications, drives research and innovation, and generates employment.

NATIONAL DEFENCE VISION

"Malaysia as a secure, sovereign and prosperous nation"

NATIONAL DEFENCE INTERESTS

Security	Sovereignty	Prosperity
Defending the nation's land masses, MMZ, strategic waterways, airspace and critical lines of communication	Preserving independence and preventing external interference	Protecting economic prosperity, development and growth opportunities, including interests abroad

NATIONAL DEFENCE OBJECTIVES

Developing multiple domain capabilities to detect, deter and deny any threat to Malaysia's national defence interests along the concentric layers of the core, extended and forward areas	Enhancing Malaysia's internal resilience through comprehensive defence by adopting the whole-of-government and whole-of-society approaches	Strengthening Malaysia's defence capacity and security through credible partnerships, chiefly by promoting innovative initiatives, deepening cooperation and pursuing multi-level defence engagements in a complementary manner	Advancing Malaysia's defence industry as an economic catalyst and a niche-based self-reliance stimulant through progressive programmes in developing the nation's defence science, technology and industry	Ensuring good governance practices in strengthening the defence sector by consolidating transparency, accountability and excellence in pursuing organisational transformations

Figure 1: National Defence Framework
Source: Malaysia Defence White Paper 2020

Recognizing the significance of the NDI, the Malaysian Ministry of Defence has prioritized the development of a National Defence Industry (NDI) Framework, set to be launched at the Langkawi International Maritime and Aerospace Exhibition (LIMA) 2025 (MOD, 2024) as promotion of it is an example of strategy to boost NDI by anticipated collaborative efforts with credible strategic partners to achieve nation's objectives (Focus 5) (refer Figure 2). This framework aims to create a competitive local defence sector through strategic partnerships, technological advancement, and industry-wide collaboration.

Figure 2: Fifth Focus - Developing a Competitive and Resilient Local Defence Industry
Source: The Ministry of Defence Outlined during
Defence Minister's New Year's Address 2025

Malaysia's Standing in Regional Power

Malaysia has demonstrated notable improvements in the 2024 Asia Power Index, particularly in diplomatic influence, which saw the greatest gain (+9.1). The country also improved in cultural influence (+4.2), military capability (+1.5), economic capability (+1.1), economic relationships (+0.9), and future resources (+0.8). However, Malaysia experienced a decline in resilience (-1.2) and defence networks (-2.4), highlighting key areas for improvement (Patton, Jack Sato, & Herve Lemahieu, 2024) (refer figure 3).

Resilience, in this context, refers to a nation's ability to deter external threats through internal stability, resource security, and geopolitical strength. Meanwhile, defence networks measure alliances, regional defence diplomacy, and arms transfers, acting as multipliers for military capability (Patton, Jack Sato, & Herve Lemahieu, 2024). Malaysia's scores decline in these areas suggests an urgent need to bolster its defence networks and resilience to safeguard national security and sovereignty.

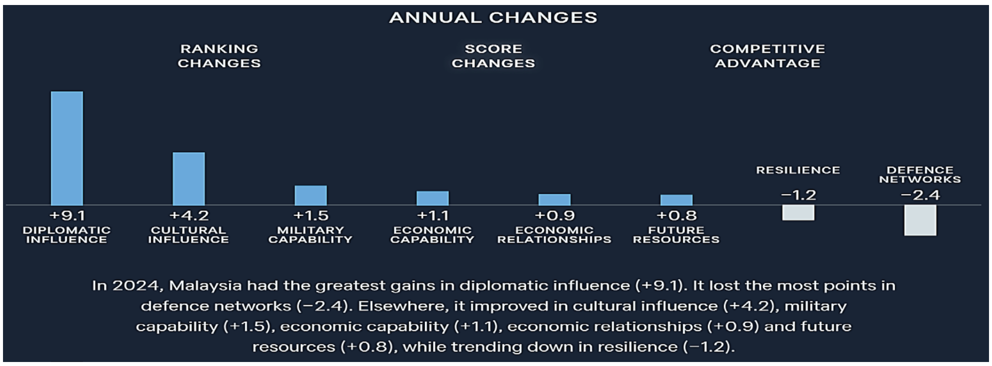

Figure 3: Score Changes for Malaysia in 2024
Source: Lowy Institute, Asia Power Index 2024 Edition

Ranked 11th out of 27 countries in Asia for Comprehensive Power with a score of 19.6 out of 100, Malaysia remains a recognized middle power. It is the fourth-most powerful nation in Southeast Asia, following Singapore, Indonesia, and Thailand. Despite limited defence resources, Malaysia wields more influence in the region than expected, as indicated by its positive power gap score (Patton, Jack Sato, & Herve Lemahieu, 2024). To strengthen its resilience and defence networks, Malaysia must leverage its growing diplomatic influence by enhancing local defence manufacturing, expanding Defence Industrial Collaboration (DIC), and advancing defence diplomacy. The National Defence Industry (NDI) is pivotal in these efforts, serving as a key enabler for national security, resilience, and sustainable economic growth. By prioritizing these areas, Malaysia can reinforce its strategic standing in the region while ensuring long-term stability and defence capability.

National Defence Industry: Driving Economic Resilience

A resilient economy can withstand and recover from crises through adaptability, flexibility, and diversification (Walker, 2012) (Nelson, 2020). National resilience is crucial for sustainable economic progress, as it enables a country to endure challenges and recover effectively. A sustainable economy goes beyond financial profit, integrates social and environmental considerations, focusing on job creation, income distribution, and technological innovation (Rusland & Nur Surayya Mohd Saudi, 2023). Achieving national resilience requires a balanced approach that ensures long-term stability and equitable progress.

Malaysia's National Defence Industry (NDI) is vitally important in providing sustainability and economic resilience. The investment made in improving the NDI that include research and development (R&D), military technology transfer and innovation encourage advancements in defence as well as civilian industries in transportation, energy and communications. The NDI also works towards fulfilling the objectives of creating new job opportunities and cultivating small and medium enterprises (SMEs), while partnering with educational institutions, thereby contributing to the overall industrial development. Globally, the defence sector is a major contributor to national economies, as seen in the U.S. aerospace and defence industry, which generates billions in substantial tax and employment (Bowman, 2012), showcasing how a strong defence industry can contribute to national economic resilience.

By leveraging its defence industry, Malaysia can enhance economic security, reduce dependence on foreign suppliers, and ensure sustainable growth. Strengthening the NDI will reinforce national resilience, drive technological advancements, and create economic opportunities, positioning Malaysia as a competitive player in both regional and global markets.

Overview of Malaysia's Defence Industry

Malaysia's defence industry is categorized as a 'third-tier' arms producer, primarily manufacturing small arms, ammunition, armoured vehicles, and small-sized ships while relying on licensed production and imported components (Bitzinger, 2015). Since the 1970s, Malaysia has progressed from basic maintenance and repair to limited design and manufacturing, particularly in aerospace, maritime, and ICT sectors (Balakrishnan K. , 2008). The number of defence companies has grown significantly, with over 204 local firms registered under the Malaysian Industry Council for Defence, Enforcement, and Security (MIDES) (MIDES) (See Figure 4). However, most remain assembly-focused, with minimal R&D capabilities. Despite strong ties with the Ministry of Defence (MOD), local firms rely heavily on government contracts, highlighting a need for diversification through commercial markets and dual-use strategies (Balakrishnan, Kogila, & Nadira Treesna, 2021).

LIST OF COMPANIES REGISTERED WITH THE MALAYSIAN DEFENCE, ENFORCEMENT AND SECURITY INDUSTRY COUNCIL (MIDES)				
SERIAL	COMPANY	ADD3	STATE	COUNTRY
1	3F Resources Sdn Bhd		KUALA LUMPUR	MALAYSIA
2	ADPR Consult (M) Sdn Bhd		Kuala Lumpur	MALAYSIA
3	Advanced Air Traffic Systems (M) Sdn Bhd	SHAH ALAM	Selangor	MALAYSIA
4	Advanced Air Traffic Systems (M) Sdn Bhd	SHAH ALAM	Selangor	MALAYSIA
5	Advanced Defence Systems Sdn Bhd	Kuala Lumpur	Kuala Lumpur	MALAYSIA
6	Advanced Defence Systems Sdn Bhd	Kuala Lumpur	Kuala Lumpur	MALAYSIA
7	Aero Precision Resource Sdn Bhd	Shah Alam	Selangor	MALAYSIA
8	Aerospace Technology System Corporation	KUANTAN	Pahang	MALAYSIA
9	Aerospace Technology System Corporation	KUANTAN	Pahang	MALAYSIA
10	Aerotree Defence & Services Sdn Bhd	Kuala Lumpur	KUALA LUMPUR	MALAYSIA
11	Airestec Sdn Bhd	1 Jalan Desa Kiara, Mon't Kiara	Kuala Lumpur	MALAYSIA
182	System Consultancy Services Sdn Bhd		KUALA LUMPUR	MALAYSIA
183	System Enhancement Resources & Technologies S	SEREMBAN	Negeri Sembilan	MALAYSIA
184	Systematic Aviation Services Sdn Bhd	SUBANG	Selangor	MALAYSIA
185	Talent Global Sdn Bhd	Seksyen U5 Shah Alam	Selangor	MALAYSIA
186	Techtisan Sdn Bhd	Petaling Jaya	Selangor	MALAYSIA
187	Teknik Padu Sdn Bhd		KUALA LUMPUR	MALAYSIA
188	Teknomatrik Sdn Bhd	Lumut	Perak	MALAYSIA
189	Teliti Computers Sdn. Bhd.	Pusat Dagang Setia Jaya No. 9Jalan PJS 8/	PETALING JAYA	MALAYSIA
190	Tractors Petroleum Services Sdn Bhd	Taman Perindustrian Puchong Utama	Selangor	MALAYSIA
191	Transmaris Techno-Sciences Sdn Bhd	Kuala Lumpur Sub Urban Centre	KUALA LUMPUR	MALAYSIA
192	UMW Corporation Sdn Bhd	SHAH ALAM	Selangor	MALAYSIA
193	UMW Corporation Sdn Bhd	SHAH ALAM	Selangor	MALAYSIA
194	Unmanned Systems Technology Sdn Bhd		Melaka	MALAYSIA
195	Vas Aero (M) Sdn Bhd	SHAH ALAM	Selangor	MALAYSIA
196	Vas Aero (M) Sdn Bhd	SHAH ALAM	Selangor	MALAYSIA
197	Vita Berapi (M) Sdn Bhd		KUALA LUMPUR	MALAYSIA
198	Wasilah Holdings Sdn Bhd		KUALA LUMPUR	MALAYSIA
199	Weldan Marine Services Sdn Bhd	Sandakan	Sabah	MALAYSIA
200	Weststar LDV Sdn Bhd		KUALA LUMPUR	MALAYSIA
201	Wiraweb Sdn Bhd	Off Jalan Klang Lama	KUALA LUMPUR	MALAYSIA
202	XSPec Technology Sdn Bhd	SUBANG JAYA	Selangor	MALAYSIA
203	Xybase Sdn Bhd	PETALING JAYA	Selangor	MALAYSIA
204	Zetro Aerospace Corporation Sdn. Bhd.	SEPANG	Selangor	MALAYSIA

Figure 4: List of Companies Registered with the MIDES (2024)

Source: Malaysian Industry Council for Defence, Enforcement and Security (MIDES) Registered members (2024)

Comparative Analysis

Malaysia, ranked 10th in the region for self-reliance (Béraud-Sudreau, Liang, Wezeman, & Sun, 2022) lags behind its neighbours like Singapore, whose government-owned ST Engineering ranks 58th among the top 100 arms-producing companies globally (SIPRI, 2024) (refer Figure 6 and 7). Malaysia, however, does not have any companies listed in the top 100, indicating its limited capacity in arms production compared to regional powerhouses. While Singapore, Japan, and South Korea have established strong domestic industries, Malaysia's defence industry remains far behind, underscoring the challenges in advancing indigenous production capabilities and achieving greater regional and global competitiveness.

Table 1.1. Regional ranking for arms exports, arms imports and military spending in the Indo-Pacific region

Country	Regional rank as exporter, 2016–20	Regional rank as importer, 2016–20	Largest supplier (share of total arms imports)	Military spending, 2021 (current US$ m.)	Regional rank in spending, 2021
Australia	3	2	United States (69%)	31 754	5
China	1	3	Russia (77%)	293 352	1
India	4	1	Russia (54%)	76 598	2
Indonesia	5	8	United States (23%)	8 259	9
Japan	14	6	United States (97%)	54 124	3
South Korea	2	4	United States (58%)	50 227	4
Malaysia	n.a.	16	Spain (32%)	3 830	13
Pakistan	13	5	China (72%)	11 305	8
Singapore	7	9	France (43%)	11 115	7
Taiwan	12	15	United States (100%)	12 958	6
Thailand	15	10	South Korea (25%)	6 605	10
Viet Nam	11	7	Russia (66%)	. . (5 500 in 2018)	. .

n.a. = not applicable.

Note: Regional ranking is based on the 44 jurisdictions in Asia and Oceania as defined in SIPRI databases, 'Regional coverage', [n.d.].

Sources: SIPRI Arms Transfers Database, Mar. 2022; and SIPRI Military Expenditure Database, Apr. 2022.

Figure 5: Regional Ranking for Arms Exports, Arms Imports and Military Spending in the Indo-Pacific Region

Source: SIPRI Arms Transfer Database, Mar. 2022; and SIPRI Military Expenditure Database, Apr. 2022

Rank[a]		Company[b]	Country[c]	Arms revenues ($ m.)		Change in arms revenues, 2022–23 (%)	Total revenues ($ m.)	Arms revenues as a % of total revenues
2023	2022			2023	2022[d]		2023	2023
58	57	ST Engineering	Singapore	$2,230	$2,360	–5.5% ▼	$7,520	29.7%

Figure 6: Singapore-ST Engineering Ranked in 58th Place of Top 100 Ranking Defence Industry in the World 2023

Source: The SIPRI Top 100 Arms-Producing and Military Services Companies, 2023

Country[a]	No. of companies	Arms revenues ($ m.)		Change in arms revenues, 2022–23	Share of total Top 100 arms revenues
	▼	2023	2022		
China	9	$102,890	$102,202	0.7% ▲	16.3%
Japan	5	$9,990	$7,376	35.4% ▲	1.6%
South Korea	4	$10,980	$7,920	38.6% ▲	1.7%
India	3	$6,740	$6,368	5.8% ▲	1.1%
Singapore	1	$2,230	$2,359	–5.5% ▼	0.4%
Taiwan	1	$3,220	$2,529	27.3% ▲	0.5%
Total	23	$136,050	$128,754	5.7% ▲	21.5%

Figure 7: Singapore and Other 5 Countries in Asia and Oceania Region Ranked in Top 100 Ranking Defence Industry in the World 2023

Source: The SIPRI Top 100 Arms-Producing and Military Services Companies, 2023

Malaysia's Defence Growth Nexus

The defence-growth nexus examines the relationship between a country's defence expenditure and its economic growth (Soderberg, 2023). In Malaysia, military spending increased to USD 4.006 billion in 2023 from USD 3.668 billion in 2022 (IISS, 2024) (refer figure 8). However, this remains significantly lower than Singapore's USD 13.401 billion defence budget for 2023 (Patton, Jack Sato, & Herve Lemahieu, 2024). While Malaysia allocates less than 1% of its GDP to defence, Singapore dedicates approximately 6%, demonstrating its commitment to developing a strong defence industry. Singapore's strategic approach, including the establishment of ST Engineering in 1967, has contributed to its economic stability and industrial growth, reinforcing the link between a robust defence industry and national economic success.

Despite having a strong economic foundation, Malaysia has yet to leverage its defence industry as a key economic driver. Increased government investment, strategic policy reforms, and enhanced collaboration within the sector could propel the National Defence Industry (NDI) forward. By strengthening its defence capabilities and industrial base, Malaysia can enhance economic resilience, reduce reliance on foreign suppliers, and foster sustainable economic growth in the long term.

	Defence Spending (current USDm)			Defence Spending per capita (current USD)			Defence Spending % of GDP		
	2021	2022	2023	2021	2022	2023	2021	2022	2023
Japan	52,198	46,954	49,038	419	378	396	1.04	1.11	1.16
Korea, DPR of	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.
Korea, Republic of	46,258	42,287	43,844	894	816	844	2.54	2.53	2.57
Laos	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.	n.k.
Malaysia	3,828	3,668	4,006	114	108	117	1.02	0.90	0.93
Maldives	92	102	110	236	262	282	1.72	1.65	1.57
Mongolia	100	91	92	31	28	28	0.67	0.55	0.51
Myanmar	3,409	2,083	3,051	60	36	53	5.23	3.15	4.08
Nepal	418	422	424	14	14	14	1.13	1.03	1.03
New Zealand	3,269	3,299	3,735	655	653	731	1.31	1.36	1.50
Pakistan	10,300	9,768	11,057	43	40	45	2.96	2.61	2.76
Papua New Guinea	87	98	98	12	10	10	0.33	0.31	0.31
Philippines	6,805	7,058	6,177	61	62	53	1.74	1.75	1.43
Singapore	11,433	12,346	13,401	1,949	2,085	2,243	2.70	2.64	2.69
Sri Lanka	1,548	1,156	1,267	67	50	54	1.75	1.54	1.69

Figure 8: Asia Countries' Defence Spending/ Defence Budget (2022-2024)
Source: IISS The Military Balance 2024

Navigating Challenges & Strategies for Malaysia's Defence Industry

Malaysian defence industry is stunted by number of structural and governance issues (Abdullah & Haliza Mohd Zahari, 2023). The Defence White Paper (DWP) implementation. The DWP (Defence White Paper) implementation has been strategically neglected for a long time due to disruptive political instability such as such as erratic changes in leadership and policies. At the Ministry of Defence (MINDEF) level, an effective leadership determines policy continuity, aligning defence spending with national security priorities and fostering industry development. The experience of Türkiye and Indonesia shows defence industry advancement due to strong leadership with centralizing decision-making (Demir, 2020).

Misalignment of national defence policies and the framework for their implementation presents another major issue. Absence of clear strategical frameworks that defined steps and set milestones along with necessary key performance indicators (KPIs) poses difficulties for local defence contractors (Abdullah & Haliza Mohd Zahari, 2023). Political instability has made initiative delays worse; the Malaysia Defence City initiative has yet to be completed. The country requires a clearly defined and comprehensive policy framework coupled with consistent procurement policies guided by self-reliance in defence production to resolve these issues.

Another problem is pertaining to ambiguous roles of the government in aiding local defence companies. Inconsistency in contracts and limited R&D investment as well as the absence of long-term partnerships, hinder the growth of the industry (Abdullah & Haliza Mohd Zahari, 2023). Many local firms struggle due to uncertain future contracts, limiting their ability to scale and innovate. "Buy Malaysian Product First" initiative tend to only scratch the surface and need to go a step further by fulfilling local procurement rules. These measures together would ensure that local manufacturers receive better defined procurement criteria and more comprehensive strategic partnerships with high-tier defence nations.

Bureaucracy remains a crucial barrier in regard to procurement of defence projects and the approval of its projects. The slow R&D approval stems from a lengthy process and is exacerbated by convoluted tendering steps, which in turn stultifies the growth of the industry (Abdullah & Haliza Mohd Zahari, 2023). Moreover, transparency issues further diminish the trust in procurement practices while allegations of favouritism and corruption are still rampant. Accomplishing efficiency in the procurement of the defence requires actions such as streamlining of regulations, reduction of administrative red tape and the promotion of fair competition in those areas.

Additionally, the industry faces budget constraints, with Malaysia's defence spending trailing behind regional counterparts like Singapore and Indonesia (Patton, Jack Sato, & Herve Lemahieu, 2024). In 2024, the security sector, which comprises defence subsectors, receives 13.95% of Development Expenditure (DE) (Ministry of Finance, 2024) (refer figure 10), with an average of MYR3 billion allocated for the Ministry of Defence over the past decade. While industry players understand that fiscal limitations exist given the government's priorities in sectors like healthcare and education, adopting a strategic approach such as prioritizing domestic R&D, supporting local expertise, and fostering partnerships can optimize budget allocations and strengthen defence capabilities.

TABLE 3.2. *Federal Government Development Expenditure by Sector, 2022 – 2024*

SECTOR	RM MILLION			CHANGE (%)			SHARE (%)		
	2022	2023[1]	2024[2]	2022	2023[1]	2024[2]	2022	2023[1]	2024[2]
Economic	**39,115**	**55,035**	**45,231**	***25.0***	***40.7***	***-17.8***	***54.6***	***56.7***	***50.3***
of which:									
Transport	16,560	17,565	19,128	*27.5*	*6.1*	*8.9*	*23.1*	*18.1*	*21.3*
Trade and industry	2,308	2,749	3,611	*31.4*	*19.1*	*31.4*	*3.2*	*2.8*	*4.0*
Energy and public utilities	2,359	3,240	3,070	*11.6*	*37.4*	*-5.2*	*3.3*	*3.3*	*3.4*
Agriculture	2,548	3,261	3,116	*3.4*	*28.0*	*-4.4*	*3.6*	*3.4*	*3.5*
Environment	1,736	2,673	3,330	*32.5*	*54.0*	*24.6*	*2.4*	*2.8*	*3.7*
Social	**21,132**	**26,546**	**28,320**	***-6.5***	***25.6***	***6.7***	***29.5***	***27.4***	***31.5***
of which:									
Education and training	10,029	13,557	14,268	*21.9*	*35.2*	*5.2*	*14.0*	*14.0*	*15.9*
Health	4,412	4,916	6,143	*-49.4*	*11.4*	*25.0*	*6.2*	*5.1*	*6.8*
Housing	1,653	2,114	1,998	*21.5*	*27.9*	*-5.5*	*2.3*	*2.2*	*2.2*
Security	**8,210**	**11,518**	**12,554**	***9.5***	***40.3***	***9.0***	***11.5***	***11.9***	***13.9***
General administration	**3,117**	**3,901**	**3,895**	***8.5***	***25.1***	***-0.2***	***4.4***	***4.0***	***4.3***
Total	**71,574**	**97,000**	**90,000**	***11.4***	***35.5***	***-7.2***	***100.0***	***100.0***	***100.0***
% of GDP	***4.0***	***5.2***	***4.6***						

[1] Revised estimate
[2] Budget estimate, excluding Budget 2024 measures
Source: Ministry of Finance, Malaysia

Figure 10: Federal Government Development Expenditure by Sector, 2022-2024
Source: Ministry of Finance, Malaysia

The shortage of skilled professionals is another pressing issue. Many graduates lack the practical experience needed to work with advanced defence technologies. Unlike South Korea, where university programs prepare students for immediate employment in defence roles (Abdullah & Haliza Mohd Zahari, 2023), Malaysia's educational framework does not fully align with industry needs. To bridge this gap, investment in Technical and Vocational Education and Training (TVET) is necessary, along with leveraging the expertise of military veterans to enhance workforce development.

Weak governance structures and institutional inefficiencies further hinder industry progress. Organizations such as the Defence Industry Division (DID) and the Science and Technology Research Institute for Defence (STRIDE) have limited influence over procurement decisions and struggle with resource constraints (Balakrishnan K. , 2008). Additionally, Malaysia's procurement system has suffered from corruption scandals noted by the Littoral Combat Ship (LCS) project, pinpointing the need for greater transparency and accountability (Ministry of Defence, 2022). International best practices show the extent to which good governance bolsters growth in the defence industry. Turkey has successfully minimised corruption while advancing industrial growth (Bucur-Marcu, Philipp Fluri, & Todor Tagarev, 2009) and South Korea's move to civilian control has boosted military procurement transparency (Kim & David Kuehn, 2022). Strengthening Malaysia's defence governance through clear policies, institutional reforms, and enhanced civilian education on military affairs is crucial for long-term growth. Resolving these concerns will increases Malaysia's potential for establishing a more resilient, competitive and self-sufficient defence industry, thereby enhancing national security while contributing to economic sustainability.

Conclusion

Resilience and sustainability of the economy on the other hand, has the capability to withstand shocks and recover from disruptions while ensuring longitudinal growth and stability. National resilience goes beyond purely focusing on the financial performance of the country, as it incorporates social, environmental and technological factors into the economic policies of the nation. In relation to this, Malaysia's National Defence Industry (NDI) is vital towards building the economic resilience of the country through investments in R&D, technology transfer and innovation. The industry aids large scale employment, strengthens Small and Medium Sized Enterprises (SMEs) and promotes interdisciplinary collaboration with academic institutions, thus aiding to the industrial development.

In addition, a robust defence industry also improves the national economic security by reducing dependency on foreign suppliers thereby ensuring growth in a sustainable manner over the long term. For strengthening the NDI, government of Malaysia should have a well-defined policy framework and enforce "Buy Malaysian Product First" policy effectively with the issuance of a buyback guarantee framework that enables long-term contracts to be locked in by local entities to ensure financial stability. Sponsored strategic alliances with local defence contractors and foreign primes, streamlining procurement processes and prioritizing innovative R&D will be key to strengthening the industry's competitiveness.

Aside from the economic advantages such as job creation and heightened export activities, a robust NDI fundamentally enables more efficient operational strategies for the Malaysian Armed Forces (MAF) and boosts military capabilities, as well as the national security. Ultimately, a well-developed and sophisticated defence industry will serve as a foundation for economic resilience and self-reliance, thus supporting the overarching Malaysia's grand strategy of defence and the 'Malaysia Madani' vision. Malaysia can build a stronger NDI that serves national security while ensuring enduring economic growth by prioritizing sustainable and people-centric growth development programs.

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NAVIGATING MARITIME LOGISTICS RISKS: LESSONS FROM THE SRI LANKA NAVY'S CRISIS MANAGEMENT STRATEGIES

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Abstract

Sri Lanka's strategic position in the Indian Ocean underscores its importance as a maritime logistics hub. However, this location also exposes it to substantial risks, such as shipping accidents, transnational organized crime, and environmental challenges. This paper highlights the vulnerabilities in Sri Lanka's maritime domain, focusing on case studies of the X-Press Pearl and MT New Diamond incidents. A literature review explores the impact of geopolitical tensions, environmental regulations, technological disruptions, and climate risks on maritime logistics. The study employs a mixed-method approach, analyzing policies and case studies to assess the crisis management strategies adopted by the Sri Lanka Navy. Key findings reveal gaps in infrastructure and preparedness, which have hindered timely responses to maritime crises. The research emphasizes the importance of Maritime Domain Awareness and regional collaborations to address these issues effectively. Recommendations include implementing stringent maritime laws, enhancing coastal and aerial surveillance, fostering interoperability with sister forces and international navies, and maintaining a non-aligned foreign policy. Investments in advanced technology, specialized training, and indigenous research are crucial for bolstering the Sri Lanka Navy's capacity to mitigate risks and safeguard Sea Lines of Communication. Furthermore, integrating operational responsibilities across security agencies can optimize resources and ensure comprehensive maritime security. Sri Lanka's ability to navigate these challenges while maintaining a robust maritime logistics framework is critical for its economic and strategic resilience. By adopting these measures, the country can strengthen its maritime capabilities, ensuring sustainability and resilience in an increasingly volatile global maritime environment.

Key words: Maritime logistics risks, crisis management, Sri Lanka Navy

Introduction

The strategic location of Sri Lanka in the Indian Ocean Region (IOR) positions it as a crucial hub for global maritime logistics (Liyanagamage, 2018). However, this prominence also exposes the nation to a multitude of logistical risks and security challenges within its extensive maritime domain, ranging from illegal, unreported, and unregulated (IUU) fishing, drug trafficking, and human smuggling (Liyanagamage, 2018) to the more recent threats of environmental disasters as starkly illustrated by the

New Diamond caught fire and sank 38 nautical miles off the east coast of Sri Lanka and the MV X-Press Pearl incident (Premasiri and Chandrasena, 2023). As an island nation situated in a major naval route, Sri Lanka is particularly vulnerable to maritime disasters (Liyanagamage, 2018).

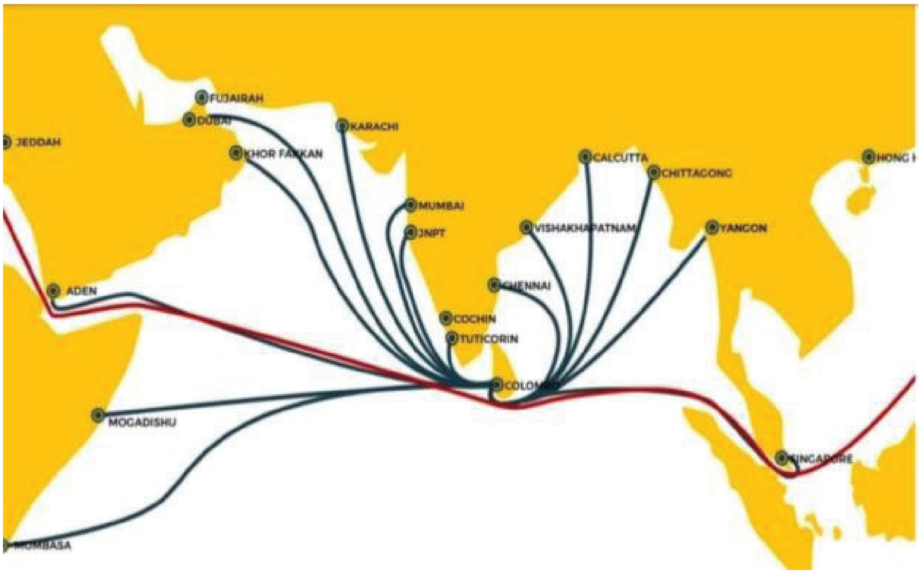

Figure 1: Major Shipping Lanes Networked with Sri Lanka
Source: www.researchgate.net

The Sri Lanka Navy (SLN) plays a pivotal role in navigating these complex risks, adapting its strategies to ensure maritime security and respond to crises that can significantly impact the flow of logistics (Liyanagamage, 2018). This article examines the major logistical risks encountered in Sri Lanka's maritime environment and explores the crisis management strategies employed by SLN, aiming to draw valuable lessons for the broader logistics community.

The Sri Lanka Navy must implement well-defined strategies and ensure that their personnel are thoroughly trained and equipped with the necessary tools. Without these measures, it becomes exceedingly challenging to manage and overcome maritime disasters. This includes continuous training programs for naval personnel, investment in advanced maritime equipment, and the development of comprehensive disaster response plans. By doing so, the Sri Lanka Navy can enhance its capability to respond to and mitigate the impacts of maritime accidents, thereby safeguarding both marine life and coastal communities.

Literature Review

Maritime Logistics Risks

Maritime logistics risk can be identified as potential challenges, hazards, or uncertainties that can disrupt the smooth flow of goods and operations in maritime logistics (Mokhtari and Ren, 2014). The following reasons can be identified as the factors affecting maritime risk.

1. **Geopolitical Tensions and Trade Policies**. One of the most significant risks to the maritime logistics industry is the volatility of geopolitical tensions and trade policies. It directly impacts maritime logistics. Tariff disputes, sanctions, and trade wars can disrupt shipping routes, alter trade flows, and increase operational costs. For instance, recent tensions between major trading nations have led to shifts in global trade patterns, impacting the demand for maritime transport and creating uncertainty for logistics providers (Gao, 2024).

2. **Environmental Regulations and Sustainability**. The push for environmental sustainability is driving significant changes in the maritime logistics industry. Stricter environmental regulations, such as the International Maritime Organization's (IMO) sulfur cap and decarbonization targets, require shipping companies to adopt cleaner fuels and invest in eco-friendly technologies. Compliance with these regulations can increase operational costs and necessitate substantial investments in new equipment and infrastructure.

3. **Technological Disruptions and Cybersecurity**. The rapid advancement of technology presents both opportunities and risks for the maritime logistics industry. Innovations such as blockchain, Internet of Things (IoT), and artificial intelligence (AI) have the potential to enhance efficiency, transparency, and reliability in supply chain operations. However, the adoption of new technologies also introduces vulnerabilities to cyberattacks and data breaches.

4. **Economic Uncertainty and Market Fluctuations**. Economic instability and market fluctuations pose significant risks to the maritime logistics industry. Factors such as fluctuating fuel prices, currency exchange rates, and global economic slowdowns can impact shipping demand, freight rates, and profitability (Gao, 2024). The COVID-19 pandemic, for example, has highlighted the vulnerability of global supply chains to unexpected economic shocks.

5. **Climate Change and Extreme Weather Events**. Climate change and extreme weather events present growing risks to the maritime logistics industry. Rising sea levels, increased frequency of hurricanes, and unpredictable weather

patterns can disrupt shipping routes, damage infrastructure, and delay cargo deliveries. These events have a significant impact on the international maritime shipping supply chain (Gao, 2024). These environmental challenges necessitate proactive risk management and contingency planning.

6. **Increasing complexity and ambiguity of the security environment at sea**. The Maritime Doctrine of Sri Lanka highlights that terrorism has significantly increased. Terrorism is one of the major threats in the maritime domain. Unlike traditional military scenarios with clearly defined adversaries, these non-military asymmetrical threats often require more than pure military undertakings to be defeated. The maritime domain not only serves as a medium for the movement of threats but also presents a broad array of potential targets. Sri Lanka's strategic location in the IOR is particularly susceptible to these emerging threats. Particularly concerning non-military, transactional, and asymmetric threats(Br, 2020).

7. **Shipping accidents**. One of the other maritime logistics risks can be identified as shipping accidents. The risk factor for the marine environment, such as pollution from shipping accidents like the MV X-Press Pearl disaster in 2021 (Rathnasri, 2021). The shipping accidents highlight the severe impact of maritime activities on the marine environment (Arachchige et al., 2021).

Sri Lanka's Strategic Importance and Vulnerability in Maritime Logistics

Sri Lanka's strategic geographical location in the Indian Ocean, near major Sea Lines of Communication (SLOCs) and its ambition to become a global logistics hub and a key point on the Maritime Silk Route, remains central to its maritime profile (Arachchige et al., 2021). The port of Colombo continues to be a crucial deep-water port in South Asia. The country has ambitions to become a major logistics hub in the region and a transshipment port for the Bay of Bengal (Warna, Wanni and Kankanamge, 2023). This strategic importance simultaneously exposes Sri Lanka to significant maritime security concerns and vulnerabilities (Liyanagamage, 2018). The same study highlights that the disruption of sea lines of communication and trade is a major potential non-conventional maritime threat in the IOR. According to the maritime doctrine of Sri Lanka, SLN is responsible for nurturing a stable environment at sea to ensure the freedom of navigation and commerce.

Regulatory Frameworks and Governance

International regulations like Safety of Life at Seas Convention (SOLAS) are crucial for managing dangerous goods and preventing spills (Karlsson, 2022). However, the X-Press Pearl incident has led to criticism that these regulations may be outdated for modern ultra-large vessels. Sri Lanka's Marine Pollution Prevention Act No. 35 of 2008 provides the legal basis for enforcing international conventions such as the United

Nations Convention on the Law of the Sea (UNCLOS) and the International Convention for the prevention of pollution from ships (MARPOL). The Act establishes liability for ship owners and operators in cases of pollution (Liyanagamage, 2018; Arachchige et al., 2021).

Crisis Management in Maritime Logistics

Crisis management in maritime logistics is crucial for maintaining seamless operations and ensuring the resilience of the global supply chain (Koritarov, Dimitrakieva and Vaptsarov, 2024). Maritime transportation is a vital component of worldwide commerce, handling about 80% of it (Kim et al., 2024). Disruptions in this sector can have significant economic consequences (Liyanagamage, 2018). Crisis management in maritime logistics necessitates a complete approach that includes risk assessment, proactive planning, efficient communication methods using both traditional and digital media, well-trained staff, and adherence to ethical principles. Building resilience in this crucial industry requires learning from previous disasters and adapting to new challenges.

Methodology

The researcher employed the desk review method to review international reports, published research papers, web articles, handbooks, case studies, and etc. as source being the existing knowledge base which allows for a comprehensive analysis of this paper.

a. Research approach: Case study analysis and policy review focusing on Sri Lankan context

b. Using a mixed-method approach, this study examines how maritime logistics important, risk pertain to Sri Lanka, and crisis management strategies implement by Sri Lanka Navy. Case studies provide an in-depth understanding of shipping accidents pertaining to the maritime logistics risks.

c. Selection criteria for case studies and policy documents relevant to the Sri Lankan Context

Relevant to the study aim and Sri Lankan context will be given priority in the selection criteria for case studies and policy papers, Case studies in line with the maritime logistics risks related to theshipping accidents and harm to the environment and the economy of the country. Sri Lanka Navy played a huge role during the shipping accidents.

Data Collection

Data collected review international reports, published research papers, web articles, handbooks, case studies, and etc.

Case Studies

Two major shipping accidents in Sri Lanka

The X-Press Pearl disaster in May 2021 involved a cargo ship catching fire near Colombo, releasing toxic chemicals, oil, and plastic pellets into the ocean. Similarly, in September 2020, MT New Diamond, an oil tanker carrying crude oil, caught fire off the eastern coast, raising fears of an oil spill.

The X-Press Pearl fire: The X-Press Pearl fire in May 2021 is repeatedly identified as a major maritime disaster in Sri Lanka's recent history, underscoring this vulnerability (Karlsson, 2022). The same study identified as this event is described as a "new kind of oil spill" due to the toxic mix of plastics and invisible chemicals released. The incident represented an unprecedented challenge for all maritime operations in Sri Lanka, including those conducted by the Sri Lanka Navy. The Karlsson (2022), described the environmental damage from such incidents, including pollution from plastics, chemicals, cargo residues, and oil spills, poses a very significant risk to Sri Lanka. Maritime accidents lead to pollution that severely affects marine biodiversity, including coral reefs and seagrasses (Warna, Wanni and Kankanamge, 2023). These historical maritime accidents clearly describe the risk pertaining to the maritime logistics. Furthermore, Sri Lanka is noted to have comparatively less infrastructure to combat major maritime emergencies like oil and chemical spills, exacerbating the risks (Karlsson, 2022).

Figure 2: The X-Press Pearl Fire
Source: www.hindustantimes.com

The MT New Diamond incident: The MT New Diamond a very large crude oil carrier carrying 270,000 metric tons (MT) of crude oil from Kuwait to India (Arachchige et al., 2021). On 03rd September 2020, a fire erupted in the ship's boiler room in the main engine, resulting in the death of one Filipino crew member. The initial phase of the accident occurred 38 nautical miles off the Sri Lankan shore (Arachchige et al., 2021). Although most of the crude oil cargo was unaffected by the fire, an unspecified amount of fuel oil (around 1700 MT), needed to operate on the ship, ruptured and leaked into the ocean due to the engine room fire. There was concern that 2 million barrels of oil could have entered the sea, potentially causing a complete halt of fishing in the northern and eastern seas and decades-long damage to marine life and corals.

Figure 3: The MT New Diamond Incident
Source: https://zeenews.india.com

The Sri Lankan and Indian navies conducted a joint mission and eventually extinguished the fire after several days (Arachchige et al., 2021). The incident highlighted the lack of preparedness in Sri Lanka to respond quickly to oil spills, despite its waters being heavily traversed by oil tankers. The event was considered a learning opportunity to prevent similar situations in the future. Sri Lanka Navy also get great opportunity to learn about oil spills by above incident and had a great opportunity to combined with Indian Navy to mitigate the fire.

Recommendations

Sri Lanka is situated in a strategic location of IOR. It is vulnerable to maritime logistics risk. Sri Lanka Navy is having a responsibility to protect the ocean around the country. It is advisable to implement strict maritime laws to establish effective security measures (Liyanagamage, 2018). This can help deter illegal activities that pose risks to maritime logistics.

SLN is having a good relationship with Indian Navy (IN). It is better to draft bilateral agreements with India to counter transnational organized crime (TOC) (Liyanagamage, 2018). TOC activities like drug trafficking and human smuggling can disrupt logistics. IN is one of the most powerful navies in the world. It is better to implement joint maritime patrols with India and foreign maritime patrols in territorial seas, EEZ, and beyond to enhance coastal surveillance (Liyanagamage, 2018). Increased surveillance can mitigate risks to logistics. It is advisable to maintain non-aligned status with every nation to avoid entanglement in powerful nations' strategies. This approach can ensure that Sri Lanka's maritime logistics are not unduly influenced or jeopardized by geopolitical rivalries.

Sri Lanka Navy must build interoperability with sister forces, maritime agencies, foreign navies, and coast guards (Liyanagamage, 2018).This includes intelligence and information sharing to identify and break underground networks of terrorists and TOC groups that can threaten logistics. Design and implement an efficient mechanism to protect SLOC/SLOT from TOCs. The security of sea lines of communication is vital for uninterrupted maritime logistics.

Right-size the SLN to a manageable size considering the national budget (Liyanagamage, 2018). This can free up resources to acquire new ships and surveillance equipment needed for effective maritime security and logistics protection.

Recommended implementing a hybrid navy by combining available large vessels to improve operational capability. This versatile fleet can better address diverse threats to logistics. Integrate operational capacity and responsibility of the army, air force, police, coast guard, and other security/maritime agencies. A coordinated approach enhances overall maritime security for logistics.

The SLN also works with the Sri Lanka Coast Guard (SLCG) which has key functions like deterring piracy, preventing narcotics movement, and cooperating on counterterrorism.

Most importantly, to have timely training for all naval personnel. Improve professionalism by training and recruiting well-educated personnel. Sri Lanka experienced lack of training and well knowledge during the major shipping accidents very recent history. A well-trained navy is better equipped to handle logistics risks.

Another important fact is to establish research and development expertise to utilize Sri Lankan military resources effectively. Indigenous development can lead to solutions tailored to Sri Lanka's specific logistics security needs.

Enhance coastal surveillance by combining SLN and foreign maritime patrols. Obtain support of maritime air arms of regional countries and allies to cover Sri Lanka's maritime domain as a solution to maritime blindness (Liyanagamage, 2018). Aerial surveillance is crucial for monitoring logistics routes. The SLN is also looking to recommend its naval air arm and utilize UAVs for surveillance.

The SLN should have a clear understanding of the MDSL, which is the capstone publication guiding the use of maritime power (Br, 2020).This doctrine emphasizes the role of the SLN in ensuring the security of Sri Lanka at and from the seas. Educate citizens on the consequences of illegal activities to deter participation in non-traditional security threats that can disrupt logistics.

The SLN should enhance its Maritime Domain Awareness (MDA) through participation in regional exercises, discussions, and information sharing agreements. Given Sri Lanka's strategic location as a crucial logistics service hub, the SLN's role in ensuring the safety and security of shipping operations is paramount (Br, 2020).

It is recommended to continue developing innovative technologies to ensure marine environment preservation and protection (Br, 2020). To navigate these technological risks, maritime logistics companies must prioritize cybersecurity and digital resilience. Implementing robust cybersecurity measures, conducting regular risk assessments, and investing in employee training can help protect sensitive data and critical infrastructure. Additionally, leveraging technology to enhance supply chain visibility and operational efficiency can provide a competitive edge in a rapidly changing market.

Conclusion

Sri Lanka's key location in the Indian Ocean Region offers both considerable potential and risks for maritime logistics. To overcome these difficulties, the Sri Lanka Navy (SLN) must prioritize maritime security by increasing coastal surveillance, collaborating with foreign fleets, and strictly enforcing maritime regulations. Building interoperability with sister forces, regional allies, and international maritime authorities helps successfully combat transnational organized crime and safeguard sea routes of communication. Investing in training, research, and development is critical for modernizing the SLN and improving operational capabilities while keeping the size reasonable to fit with budget limits. Furthermore, harnessing novel technology and strengthening Maritime Domain Awareness (MDA) through regional cooperation would aid in the response to rising threats to maritime logistics. By implementing these steps and being non-aligned, Sri Lanka can assure the resilience and sustainability of its marine logistics in an increasingly complex global environment.

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ANTI-CORRUPTION STRATEGIES IN MARITIME INDUSTRY: LESSONS FROM INTERNATIONAL CASE STUDIES TO THE SRI LANKAN CONTEXT

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Abstract

Global trade heavily depends on maritime operations yet faces substantial corruption risks because of elaborate operations and trade transactions with high economic value. The research paper consists of 2,800 words to analyze anti-corruption strategies by studying internationally proven models for their relevance in Sri Lanka's maritime sector. The research performs an extensive review of Sri Lanka's legal system which consists of the newly passed Anti-Corruption Act No. 9 of 2023 alongside the Bribery Act and CIABOC Act to analyze maritime corruption prevention capabilities. The paper explores maritime anti-corruption strategies based on extensive case studies from Singapore as well as Denmark and various other top maritime nations. It seeks out best practices within the scope of governance systems and technological adoption and institutional development. Numerous vulnerabilities exist within Sri Lanka's ports along with customs procedures and regulatory systems which are demonstrated through recent corruption cases and empirical evidence from the research. The study recommends specific strategies from four domains for policy implementation which consist of legal standardization adjustment and blockchain technology usage and law enforcement agency training and partnerships between public and private entities. The research generates relevant findings that offer guidance to Sri Lankan maritime authorities together with their anti-corruption partners to improve industry transparency while increasing accountability within Sri Lanka's priority maritime sector.

Keywords: Maritime corruption, anti-orruption, bribery, rule of law

Introduction to Corruption in the Maritime Industry

The maritime industry which serves as the bedrock of international commerce is vulnerable to corruption because it consists of challenging activities and valuable deals with multiple actors based in different areas of authority. In the maritime sector corruption develops through different practices such as port operation bribery as well as false claims during customs procedures and teaming up during regulatory reviews. The implementation of these deceptive schemes reduces operational trade efficiency and generates unnecessary expenses while damaging governance systems especially in developing countries because their institutional prevention measures are less effective.

The major points where corruption occurs within shipping lie at entry points to ports and also at the stage of cargo clearance because officials expect monetary payments to hasten operations or dismiss any abnormal findings. Bid rigging and kickbacks during the procurement phase of port infrastructure projects leads to increased costs since fraud exists as a high-risk practice in this sector. Maritime law enforcement agencies participate in corrupt procedures by taking payment to avoid monitoring illegal fishing and smuggling operations. The sector faces higher risks because of insufficient transparency systems combined with inadequate oversight and because of its dependence on manual operations which allow officials to exercise personal decision-making authority (CIABOC, 2023).

The extensive damage caused by maritime corruption reaches every part of the maritime domain. The existence of corruption drives-up operational expenses for businesses at the same time it decreases government revenue while simultaneously destroying public trust in institutions. The maritime sector serves as a vital economic growth engine in Sri Lanka so corruption endangers both national development and market competitiveness.

Effective countermeasures need an accurate comprehension of maritime industry corruption extent and characteristics. Research on international models along with local points of weakness helps stakeholders create specific strategies which restrain maritime sector risks and develop an ethical environment across the crucial industry.

International Legal Frameworks for Combating Corruption in Maritime Affairs

These standards define uniform corruption prevention measures through their ability to support international partnerships for maritime crime investigations. The United Nations Convention Against Corruption (UNCAC) serves as the most important framework against corruption because it enjoys ratification status from more than 180 countries including Sri Lanka. Article 9 of UNCAC directs all countries to implement measures that combat procurement transparency by requiring competitive tenders and full disclosure of contract decisions and independent monitoring requirements. Sri Lanka can retrieve international maritime corruption assets because Chapter V of the Convention provides international asset recovery tools for countries.

The ports security framework of the International Maritime Organization (IMO) supports UNCAC through its International Ship and Port Facility Security (ISPS) Code. The ISPS Code's main security focus indirectly addresses corruption by establishing standardized port procedures together with documentation practices which decrease discretionary opportunities to practice corruption. Port clearances must be digitalized according to the Facilitation Convention (FAL) of the International Maritime Organization to reduce the opportunity for humans to perform cargo inspections which are known corruption entry points. Forty percent of member states remain noncompliant with these standards during 2023.

The OECD Anti-Bribery Convention within its region makes illegal the act of transnational bribery through payments made to foreign port officials. Sri Lanka did not ratify the Convention; nevertheless, the OECD standards played a central role in the UK investigation of Rolls-Royce maritime bribery (OECD, 2020). The Maritime Anti-Corruption Network of Transparency International operates with private-sector partners to execute "collective action" projects. The Port Integrity Toolkit created by MACN allows ports in Nigeria and Argentina to simplify their operations which leads to reduced bribe requests thus proving how voluntary programs fuel actual reform efforts (IMO, 2021).

Despite these frameworks, challenges remain. Most conventions fail to address maritime issues specifically while developing countries find it difficult to execute conventions because of their limited financial resources. UNCAC requires whistleblower protection but few nations provide this protection to seafarers who report bribery occurring in ports. Inconsistencies among anti-corruption and maritime laws produce law enforcement gaps which criminals effectively utilize for registration irregularities of vessels and ownership of offshore companies (Parliament of Sri Lanka, 2023).

Singapore implemented its Prevention of Corruption Act according to both UNCAC and IMO standards which resulted in 1,200 maritime corruption prosecutions after 2015. The gradual pace of Sri Lanka to implement analogous reforms resulted in the prosecution difficulties observed during its Colombo Port bribery scandal due to delayed evidence-sharing through mutual legal assistance protocols. (Transparency International, 2022).

Maritime corruption mitigation relies on international frameworks which should integrate better with both national laws and maritime sector regulations. The implementation of OECD Convention membership and integration of IMO standards into Anti-Corruption Act No. 9 of 2023 while creating partnerships with MACN will help Sri Lanka close regulatory gaps. Since shipping operates throughout the world it needs coordinated international efforts to transform established frameworks into visible anti-corruption reductions (OECD, 2020).

Case Studies of Anti-Corruption Initiatives in the Global Maritime Industry

Anti-corruption efforts in the global maritime sector produced noteworthy achievements as well as dangerous setbacks that deliver essential knowledge to Sri Lanka. The analysis consists of three notable maritime industry cases which show different methods and resulting effects.

The anti-corruption stance of Singapore stands as one of the most thorough approaches for fighting corruption during maritime activities. The government of Singapore has maintained independence through its Corrupt Practices Investigation Bureau (CPIB) since 1952 by making it answerable solely to the Prime Minister's Office.

The Networked Trade Platform stands as Singapore's main reform tool since it digitized 95% of port documentation while the port maintained strict enforcement policies. The modern technological breakthrough in cargo clearance processes diminished human contact by 80% which substantially diminished the possibilities of bribery. (UNODC, 2019). Between 2015 to 2022 Singapore charged more than 200 maritime bribery cases which resulted in nearly 98% of defendants receiving convictions including a notable port superintendent who received a 15-year prison sentence following receipt of S$3.2 million from shipping agents.

Denmark utilizes transparency as a core principle while pursuing cooperation from the entire industry for their methods. Vessels that follow anti-corruption requirements can get lower costs and fast harbor clearance through the "Clean Shipping" certification program operated by their organization. The voluntary participation reached 82% of ships visiting Danish ports during 2023 thus indicating market forces can function alongside regulatory enforcement methods.

Global maritime operations face transformation from the Foreign Corrupt Practices Act (FCPA) of the United States because of its power to apply laws beyond national borders. The $800 million fine imposed on Rolls-Royce in 2017 stands out because the company paid for bribing government officials across seven countries which included Brazil and Thailand. The elaborate bribery activities conducted by multinational corporations through offshore intermediaries forced worldwide reforms of shipbuilding contract regulations.

Operation Car Wash conducted its investigation from 2014 to 2021 to reveal extensive port infrastructure corruption throughout Brazil representing the impact of inadequate oversight. The bribery scandal included $2.1 billion payments from bribes which led to the imprisonment of dozens of executives and political officials in connection to port construction contracts. Such a case highlighted the essential requirement to implement clear procedures during the procurement of maritime infrastructure projects (Transparency International, 2022).

The combined evidence shows that combating corruption effectively demands the establishment of independent enforcement bodies as well as technical solutions for reducing human choices and market-based compliance encouragement and international collaboration to investigate cross-border criminal activities. Port corruption reports in Singapore declined 90% throughout twenty years of implementing their integrated model of governance and Denmark achieved a 75% decrease in bribery requests through their collaborative approach starting from 2020. The combined enforcement actions of Singapore and transparency measures in Denmark create potential opportunities for Sri Lankan ports to advance their anti-corruption efforts based on community-specific conditions. (UNODC, 2019).

Best Practices and Mechanisms for Combatting Maritime Corruption

Sri Lanka can implement its national maritime anti-corruption programs by adopting mechanisms which the global maritime industry has effectively developed. Multiple measures that stem from best practices provide complete systematic solutions for dismantling corruption vulnerabilities through preventive methods and enforcement controls.

Digital Transformation of Port Operations stands as the most effective method to combat corruption. PSA International operates as a leading port authority which integrates complete digital systems to minimize human contact during essential procedures. The TradeNet platform performs automated customs clearance processing by making decisions through algorithms that cut down human discretion to 2%. The cargo tracking platform implemented by Rotterdam Port through blockchain technology produces certified transaction records that stop document alteration completely. A Port Community System similar to existing systems would lead to a dramatic decrease in corruption possibilities during cargo clearance activities and documentation handling at Sri Lankan ports. Digital systems implemented by the World Bank project to reduce bribe solicitation requests by 60-75% in ports of developing countries. (World Bank, 2023).

Security programs that protect whistleblowers have shown equal importance in enhancing integrity operations. Through its MARITIP anonymous reporting system the U.S. Merchant Marine obtains more than 500 genuine reports of corruption per year that results in successful prosecutions against offenders. The South Korean Anti-Corruption and Civil Rights Commission provides whistleblowers who report port corruption access to financial compensation that can reach $2 million together with relocation assistance. With its new Anti-Corruption Act Sri Lanka offers whistleblower protections though the legislation needs specifically designed maritime reporting systems and protection programs for maritime industry personnel. (Zhang and Wijesinha, 2021).

The collaboration between Transparency International and their Integrity Pacts in Port Contracts has successfully decreased corruption throughout major infrastructure projects. These mandatory agreements exist between governments along with bidders to operate under their terms covering:

1. Independent monitoring of procurement processes.
2. Sanctions for violations.
3. Public disclosure of all tender documents.

The Port of Santos Brazil experienced a 40 percent decrease in corruption cases through the implementation of these agreements in 2018.

Similar to other commercial entities maritime companies need viable Corporate Compliance Programs to succeed. All Maersk Line staff must complete their anti-corruption training because the company requires total employee involvement and provides specific content for their port operating employees. The “No Easy Way Out” policy issued by Maersk prohibits their staff from making any kind of facilitation payment regardless of port risk level. Global recorded cases of MAersk vessel bribe demands decreased by 82% following implementation (Perera, 2022).

The Port User Feedback Systems operate as an effective platform to identify and report acts of corruption in real time. Terminal visitors at all Ports Monitoring Office kiosks provided more than 15,000 ratings using the touchscreens every year. The collection of targetted anti-corruption data through these systems enabled operations which resulted in 55% fewer reported incidents during a three-year period(MACN, 2023).

Sri Lanka should adopt phased implementation as the most suitable method to achieve its objectives:

1. The high-risk processes of customs clearance together with license issuance must undergo urgent digitalization immediately.

2. Establishment of maritime-specific whistleblower channels.

3. Mandatory integrity pacts for port infrastructure projects.

4. Industry-wide compliance standards for shipping agents.

5. Transparent user rating systems at all terminals shall be implemented.

The combination of these measures offers the potential to cut corruption vulnerabilities by 50 to 70 percent within five years when implemented similarly to Indonesia and Mexican maritime sectors. Maritime institutions should implement technology solutions which must be supported by accountability mechanisms to achieve cultural change and reduce maritime corruption.

The Role of Public Private Partnerships in Strengthening Anti-Corruption Measures

Public Private Partnerships (PPPs) constitute a new approach to fight maritime corruption by combining government institutions with industrial partners’ individual competencies. The joint efforts between public and private entities establish powerful synergistic anti-corruption systems than single government initiatives. Multiple tested PPP models exist in maritime operations which Sri Lanka can use to fit its country-specific requirements.

1. Institutional Collaboration Frameworks

Establishing formal governance structures stands as the key factor in making PPP models successful since they guarantee continued industry-government collaboration. The Port of Rotterdam’s Integrity Platform operates as an outstanding blueprint by joining monthly working groups of port authorities together with terminal operators and shipping lines and customs officials. The platform has established common anti-corruption procedures specifically tailored for high-risk port operations such as bunkering services and cargo inspections. (CPIB, 2022). Since 2017 the initiative proved capable of meditating and reforming 83% of corruption cases before forwarding solution-resistant events to judicial prosecution. The creation of equivalent institutional structures at Colombo port and Hambantota port would create the required base for joint anti-corruption efforts.

2. Technology Co-Investment Programs

Anti-corruption technologies available to multiple parties through PPPs become affordable because participants share the financial burden together. Many of Singapore’s maritime companies participate in TradeTrust through financial contributions to develop digital authentication systems which verify shipping documents throughout supply chain operations. Within the first three years of operation the program decreased document fraud incidents by 72% yet protected commercial confidentiality. Sri Lankan PPPs need to focus on implementing blockchain-based tracking systems and automated risk assessment technology particularly relevant to their current local industry needs. (Danish Maritime Authority, 2021).

3. Joint Capacity Building Initiatives

The Maritime Anti-Corruption Network (MACN) demonstrates through its training activities how public-private partnerships improve organizational competence. The Maritime Anti-Corruption Network implemented anti-corruption training delivery alongside the Nigerian Ports Authority through partnerships that benefited more than 1,200 officials from both government and private sectors from 2019 up to 2022. By uniting government necessities with industry-made case studies, the program generated documented behavioral changes that led to significant reductions (58%) in bribery attempts at participating facilities. The proposed National Maritime University of Sri Lanka has potential as a center of excellence to deliver anti-corruption training by adopting this model.

Implementation Considerations for Sri Lanka

Proper PPP implementation depends on designing structures which prevent common programming failures.

All companies operating as PPPs need to create precise governance structures which establish authority for making decisions and paths for conflict resolution. Sustainable funding practices must exist together with a balanced financial structure that depends on minimal private sector contributions. The performance measurement system must evaluate dual components of operational efficiency improvements alongside corruption reduction achievements Businesses must receive protective legislation to defend their sensitive commercially important data exchanged through PPP operations.

Local stakeholders in the Colombo International Container Terminal's (CICT) have established an integrity pact with Transparency International which exemplifies public-private partnership potential. The partnership between stakeholders minimized irregularities in procurement by 40% through defined bidding procedures along with independent monitoring systems for terminal expansion projects. Maritime health benefits from large scale implementation of anti-corruption models throughout the sector would establish Sri Lanka as a leading regional shipping destination and bring major corruption reductions. (Auditor General's Department of Sri Lanka, 2022).

Challenges in Implementing Anti-Corruption Strategies in Sri Lanka

Even with its progressive Anti-Corruption Act No. 9 of 2023 Sri Lanka meets multiple operational and structural blocks when performing effective maritime anti-corruption implementation. The enforcement capabilities of Sri Lanka suffer because CIABOC operates with limited investigators across the nation who are not specialized in maritime sector investigations. Absolute resource inadequacy leads to profound delays because port corruption investigations need extended months to complete rather than the 6-8 months possible in Singapore. (International Chamber of Shipping, 2022).

Several obstacles create major challenges because of the fragmented nature of institutions. The operations of Colombo Port are managed by twelve separate government agencies yet there exists no coordinated system to fight corruption. The bureaucratic silos demonstrated themselves strongly in the 2021 container clearance scandal because poor inter-institutional communication allowed corruption networks to operate extensively throughout institutional divisions for years. The merchant marine administration faces ongoing vulnerabilities because its use of paper documentation for ship and crew approvals extends to 35% of manual processes that can be easily manipulated.

Cultural resistance among maritime workers makes these problems even more difficult to overcome. An extensive practice of delivering cash for fast clearance of cargo has persisted for decades and current survey data indicates that 68% of shipping agents find this payment essential for efficient operations. Labor unions working in state-run ports fought unsuccessfully against digital transformation actions which decrease their power to make decisions after the failed 2019 attempt at Jaya Container Terminal gate pass automation. The changes in government leadership in 2022 led to frequent replacements among senior authorities at ports resulting in missing opportunities for merit-based reforms (Bandara, 2023).

Lack of international cooperation in maritime corruption cases becomes problematic for Sri Lanka since it does not have mutual legal assistance treaties with its important trading partners China and India and with their specialized networks operating in port operations.

Conclusion

The study establishes that Sri Lanka advances through the Anti-Corruption Act No. 9 of 2023 to fight maritime corruption but numerous implementation difficulties still exist. Strategic anti-corruption efforts need to go beyond having strong laws alone because they need to develop institutional capabilities together with modern technological systems in addition to cultural evolutionary progress. The combination of digitalization practices along with whistleblower protection systems and public-private alliances announced in international case studies conducted in Singapore, Denmark and the U.S. helps substantially minimize corruption possibilities. The maritime sector of Sri Lanka struggles with bureaucratic fragmentation along with manual processes and established corrupt practices.

Sri Lanka should first focus on three fundamental changes including developing CIABOC with maritime investigators, accelerating digital transformation in maritime operations and creating accountable cultures through dedicated training and reporting systems. The fight against corruption throughout worldwide supply chains depends on both international partnerships and private business sector collaboration to be successful.

The study evidence demonstrates maritime de-corruption serves as both a governance requirement and an economic requirement that leads to improved trade operations and heightened foreign business investments together with strengthened regional maritime authority status. Sri Lanka can create a transparent and competitive maritime sector through the combined action of legal enforcement with technologies and institutional improvements for global best practice alignment and domestic vulnerability control.

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RISK MANAGEMENT AND CRISIS RESPONSE THROUGH ADAPTIVE TRANSPORT AND WAREHOUSE MANAGEMENT

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Abstract

The logistics industry is increasingly challenged by a wide range of risks and crises, including transportation disruptions, supply chain instability, geopolitical tensions, and cybersecurity threats. This paper explores the critical importance of risk management and crisis response in logistics, emphasizing the integration of adaptive transportation and warehouse management systems. It highlights how technologies such as Transportation Management Systems (TMS), real-time visibility tools, and cloud-based Warehouse Management Systems (WMS) can improve operational resilience, enhance supply chain visibility, and support agile responses to disruptions. The discussion underscores the growing need for proactive planning, real-time data utilization, and collaborative stakeholder involvement to maintain service levels and ensure customer satisfaction in an ever- evolving global logistics environment. By leveraging connected technologies and dynamic strategies, logistics firms can build flexible and robust operations capable of withstanding both anticipated and unforeseen challenges.

Keywords: Transportation Management Systems (TMS), real-time visibility, Warehouse Management Systems (WMS)

Introduction

The logistics sector plays a pivotal role in global supply chains, facilitating the efficient movement and distribution of goods and services. However, this dynamic industry is inherently exposed to various risks and susceptible to unforeseen crises that can disrupt operations, impact customer satisfaction, and undermine overall performance (Wu & Chaipiyaphan, 2020). From transportation delays and supply chain disruptions to natural disasters and security threats, logistics companies face a multitude of challenges that demand effective risk and crisis management strategies. Addressing these challenges in a proactive and systematic manner is essential for maintaining a competitive edge, ensuring business continuity, and fostering long -term sustainability in the logistics sector (Li et al., 2023).

In the fast-paced and interconnected world of logistics, companies encounter a plethora of risks and potential crises that can disrupt their operations and supply chain networks. Identifying these common risks and crises is essential for logistics firms to develop proactive strategies and contingency plans to safeguard their business continuity (Deng et al., 2019).

Transportation delays and disruptions are among the most prevalent risks faced by logistics companies. Unforeseen weather events, traffic congestion, or mechanical issues can cause transportation delays, impacting the timely delivery of goods to their destinations (Eygü & Karabacak,2017). Moreover, labor strikes and disruptions in transportation networks, such as port closures or railway blockades, can also lead to significant delays, further complicating logistics operations (Sawyerr & Harrison, 2020). Effective inventory management is critical for logistics companies to maintain efficient operations. However, inaccurate demand forecasting can result in overstocking or understocking, leading to excess inventory costs or lost sales opportunities (Korucuk & Erdal, 2018). Additionally, supply chain disruptions, such as delays in supplier shipments or production issues, can disrupt the flow of goods, leading to inventory shortages or surpluses, which may require careful management to avoid financial losses (Cerabona et al., 2021).

Supplier disruptions pose another significant risk for logistics companies. Suppliers facing production issues, financial difficulties, or quality problems can disrupt the supply of critical components or materials, leading to delays in production or shipments. To mitigate this risk, logistics companies must carefully evaluate their supplier relationships and establish alternative sourcing options to reduce overreliance on a single supplier (Yang et al., 2021). Logistics companies operating in multiple regions must navigate various regulatory and compliance risks. Changes in trade regulations, customs requirements, or environmental standards can impact cross- border logistics operations, requiring logistics firms to stay updated and compliant with evolving regulations. Non-compliance with regulatory requirements can lead to fines, penalties, or shipment delays, emphasizing the importance of a robust compliance framework (Sawyerr & Harrison, 2020). Geopolitical risks are inherent in global logistics operations. Political instability, civil unrest, or trade disputes in different regions can affect logistics operations and supply chain routes. Geopolitical events, such as changes in trade agreements or sanctions, can create uncertainties for logistics companies and necessitate agility in adapting to geopolitical shifts (Kumar et al., 2021).

In today's digital age, logistics companies face a growing threat of cybersecurity breaches. Cyber-attacks targeting logistics companies' IT systems and networks can lead to data breaches, operational disruptions, and financial losses. Ransomware attacks, in particular, can paralyze logistics operations and compromise sensitive information, highlighting the need for robust cybersecurity measures and incident response plans (Yu et al., 2021). Natural disasters and emergencies present a significant risk for logistics companies. Events like earthquakes, hurricanes, floods, or public health emergencies can damage infrastructure, disrupt transportation, and hinder logistics operations. To prepare for such occurrences, logistics companies should develop disaster recovery plans and establish communication protocols to ensure swift response and recovery

(Feng & Cui, 2021). Lastly, market volatility and economic fluctuations can impact logistics operations. Changes in economic conditions, currency exchange rates, or market demands can lead to fluctuations in logistics demand and costs. Managing such uncertainties requires logistics companies to remain agile and adaptable to changing market conditions (Fonseca & Azevedo, 2020).

Identifying and understanding these common risks and crises is the first step for logistics companies to build resilience and preparedness. By implementing proactive risk management strategies, developing crisis response plans, and fostering collaboration within their supply chain networks, logistics firms can enhance their ability to navigate challenges and sustain their operations in an increasingly complex and uncertain business landscape. Through effective risk and crisis management, logistics companies can position themselves for long-term success and maintain a competitive edge in the industry.

When it comes to achieving excellence across the end-to-end supply chain, there is a dependence upon a number of key stakeholders. These stakeholders include suppliers, manufacturers, transportation providers, distribution centers, and retailers, all of which need to plan ahead and collaborate to de liver customer orders on time while meeting expectations. However, no matter how much planning is involved, disruptions will always occur. These disruptions come in many forms, and whether they are major or minor in nature, will impact the overall customer experience. The right planning, and proper execution, focusing on building resilient business models, can allow companies to become agile and continue to deliver on expected service levels. There are a number of connected technologies that enable an adaptive logistics environment. These include transportation management systems (TMS), transportation visibility systems, and warehouse management systems (WMS), especially when applied to the challenges of expedited order fulfillment, rapidly changing mix of Stock Keeping Units, fulfillment through multiple channels, and heightened throughput volatility.

Discussion

1. Adaptive Transportation Management

As the global economy continues to expand, disruptions are bound to grow, whether they are related to port closures, weather, factory shutdowns, transportation shortages, trade wars, or other unforeseen events, such as global pandemics. The key is how prepared companies are to respond to these disruptions, and more importantly, how they get ahead of disruptions to ensure customer shipments remain on schedule.

From a transportation standpoint, transportation management systems and in-transit visibility tools can go a long way for companies to help maintain high customer service levels. A TMS ensures companies move freight from origin to destination efficiently, reliably, and cost-effectively. The primary reason companies buy a TMS is for freight savings. These freight savings can be attributed to simulation and network design, load consolidation, lower cost mode selections, and multi-stop route optimization. But few companies would buy a TMS if it would lead to declining service levels. A TMS maintains service levels by understanding the origin to destination lead time and using that as a constraint during the optimization run.

A contributing technology to a TMS is a visibility tool, which enables in transit visibility and improved estimated arrival times of goods. Visibility solutions are playing a larger role in the market, as real-time tracking of assets becomes more important. Suppliers of visibility solutions continue to bring in additional data streams for better shipment Estimated Time of Arrivals (ETA). Visibility solutions are becoming more necessary. The need to know where products are, whether they are on the way to the warehouse, store, or customer, is critical to ensure a positive customer experience. In addition, many companies are looking for visibility beyond simple Global Positioning System (GPS) to include details of cargo condition such as temperature, humidity, etc. This rise of visibility solutions at the container-level is helping to drive the transportation management and execution market to new heights.

Customer expectations of on-time shipments are changing as more data becomes available. These data go beyond simply knowing where an asset is; they include knowing what disruptions can impact the ETA and how to navigate through them. Disruptions such as port closures, weather, factory shutdowns, capacity shortages, and trade wars can adversely affect any com ponent and have cascading effects resulting in delayed shipments, increased costs and, adversely affected customer satisfaction.

Visibility tools enable shippers to get ahead of these disruptions and make alternative plans should problems arise. If the company is unable to make alternative plans to re-route a shipment, it can help avoid problems by contacting the customer to alert them of the problem and figure out a work around. This proactive approach to mitigating disruptions can mean the difference between a repeat customer and a lost customer.

Real-time visibility solutions are raising the prospect that machine learning can be used to improve estimated times of arrival. But machine learning can be used in other innovative ways as well. For example, in last mile routing the time a job takes to complete is dependent not just on the miles that need to be driven but also on the congestion, the type of vehicle or equipment in use, the type of product being delivered, the type of location, and whether value-added services are provided at the destination. Machine learning can be used to “learn” these constraints rather than having to do time studies and hard code these constraints into the solution.

One of the main drivers for adaptive transportation management success is the move to cloud- based infrastructure. Cloud based Software (SaaS) as a service solution is driving the transportation management and visibility market, a position that is not going to change. SaaS is available on any plat form, from anywhere, making it key for business continuity. While it features some of the same functionality as on-premise solutions, the SaaS offerings open up a larger pool of prospective clients, especially those smaller tier 2 and tier 3 customers that find the lower cost of ownership of SaaS compel ling.

2. Adaptive Warehouse Management

The expansion of e-commerce has elevated the role of warehousing in the overall customer experience. The role of retail stores in the value chain is reduced and B2B customers are starting to by-pass distributors and go straight to the manufacturer. The competitive dynamics have shifted, placing increased importance and pressures on warehousing. Product customization and availability, accompanied by accurate and timely product delivery, are now more important than ever. These competitive pressures have forced warehouses to carry a broader range of SKUs, adapt to greater order volatility, and efficiently process more individual orders in shortened fulfillment cycles. Static throughput capabilities are no longer sufficient for today's dynamic operating environment. Warehouse operations and enabling technologies must be scalable and adaptable to meet changing fulfillment volumes, SKU proliferation and mixes, and processing requirements. Furthermore, ware house management systems (WMS) must be able to handle the complexity of today's warehouses that are often fulfilling for multiple channels with dis tinct processing and handling requirements. Cloud WMS facilitates inventory visibility across facilities, which is critical for maximizing product availability while minimizing inventory carrying costs. Finally, expedited fulfillment requirements make responsiveness and reliability essential to success. Orders must be reprioritized due to more frequent carrier cut-off times, inventory must be appropriately allocated to these rush orders, and resource capacity must be assigned for proper completion of tasks. This environment requires end- to-end visibility into fulfillment processes and responsive task execution.

Conclusion

Continued excellence in logistics is dependent upon synchronized networks of suppliers, transportation providers, distribution centers, and retailers who align to deliver shipments and customer orders. One of the key components of a successful strategy is to identify and proactively navigate disruptions such as port closures, weather, factory shutdowns, and capacity shortages. A dynamic approach to transportation and warehouse management, along with a well-developed contingency plan for these disruptions, allows for an adaptive approach to the end-to-end supply chain.

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RISK MANAGEMENT AND CRISIS RESPONSE – BUILDING RESILIENCE TO GLOBAL AND LOCAL MARKET FLUCTUATIONS

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Abstract

The research proposal paper discusses the framework of global and local market volatility the function of adaptive logistics techniques in creating strong supply chains. It has become a challenge for organizations to manage continuity of operations due to increasing volatility in global supply networks. Furthermore, study focused on the strategies in which businesses responded to interruptions and variations, therefore strengthening supply chain resilience by means of adaptive logistics. Also, study is proposed to adhere on qualitative approach by interviewing important supply chain management and logistics sector industry experts in-depth. Researcher would be chosen purposive sampling method which helped to choose ten participants overall supply chain managers and logistics professionals among other things. Key themes and categories connected to adaptive logistics, resilience, and best practices were found by means of thematic analysis of the transcribed interview data. As fundamental components in developing resilience, the study underlined numerous important adaptation methods including flexibility, real-time monitoring, and varied supply sources. The results suggested that reducing the risks related to market changes depends much on adaptive logistics techniques. The study revealed important obstacles that hampered the efficient application of adaptive logistics including poor visibility and inadequate coordination among supply chain stakeholders. Companies who aggressively invested in technology, improved communication, and developed strong alliances, however, were also more suited to withstand interruptions and bounce back rapidly. All things considered, this study advanced knowledge of how adaptive logistics may be used to increase supply chain resilience. It provided useful information for companies hoping to create more responsive and agile logistics systems capable of overcoming worldwide economic obstacles. The study also added to the larger scholarly debate on supply chain resilience and adaptation tactics, therefore laying a basis for next studies in this field.

Key Words: Adaptive logistics, resilience

Introduction

The COVID-19 epidemic challenged conventional business models and upset world supply chains, therefore highlighting the vital requirement of adaptable and strong logistics systems. While some businesses shown amazing agility by using adaptive logistics techniques, others battled to keep operations running and recover from interruptions. This plus the knock-on consequences of the Russia-Ukraine crisis and growing inflation have made the global corporate scene more erratic. In this framework, one important tactic for improving supply chain resilience has become adaptive logistics. Adaptable logistics lets companies quickly change to fit evolving market conditions by using flexible, responsive systems and creative technology, therefore guaranteeing the ongoing operations. Particularly in response to the global uncertainties that have been increasingly evident in recent years (Nwankwo et al., 2024; Pavlov et al., 2019; Roscoe et al., 2022), this research attempts to investigate how adaptive logistics may enhance supply chains. It addresses the research question "How can adaptive logistics strategies build resilient supply chains in a volatile global economy?".

The research aims to pinpoint adaptive solutions that reduce hazards, minimise disturbance, and improve supply chain resilience. By means of expert interviews, actual case studies from Sri Lanka, and a comprehensive assessment of the literature, this article emphasises doable actions to improve local as well as worldwide supply chains.

Problem Justification

From natural disasters and political unrest to pandemics and cyberattacks, supply networks are becoming more complicated, linked, and susceptible in today's globalised economy. Emphasizing cost control and efficiency, traditional supply chains can lack the adaptability to resist unanticipated events (Mancini, De Camillis & Pennington, 2013). Rigid rules and overdependence on particular areas or suppliers caused many businesses to experience extreme delays, inventory shortages, and logistical bottlenecks, therefore exposing this fragility in the COVID-19 epidemic (Broadstock et al., 2021). By encouraging flexibility, decentralisation, and technology innovation, adaptive logistics shows itself as a strategic response to these problems. Adaptive logistics uses real-time data, digital platforms, and scenario modelling to react quickly to changes in consumer demand and unanticipated disruptions (Akkartal & Mızrak, 2023) unlike traditional fixed logistics systems.

Artificial intelligence (AI), blockchain, Internet of Things (IoT), and cloud computing underlie these capabilities, therefore allowing dynamic reactions to change. Sri Lanka has a strong argument in this sense for looking at adaptable logistics. The nation's reliance on foreign commerce has made its supply chains vulnerable to a range of recent events, from macroeconomic instability and the COVID-19 epidemic to port congestion and gasoline shortages. Especially in the industrial, agriculture, and retail sectors, these difficulties have highlighted important weaknesses (Manathunge et al., 2021). Through investigating adaptive logistics solutions in this framework, the study not only adds to the worldwide conversation on supply chain resilience but also offers practical advice for local governments and companies trying to improve operational continuity and resilience.

Given the pressing need for strong supply networks able to resist world uncertainty, this study is relevant and vital. It looks at how in tumultuous conditions adaptive logistics could both be a defense measure and a competitive advantage.

Research Objectives and Research Questions

With specific focus on policies relevant in unpredictable global and local settings, including that of Sri Lanka, this paper attempts to analyse the function of adaptive logistics in improving the resilience of supply chains. The study will look at how companies are including adaptive logistics into their processes and how these strategies help them to react to interruptions.

Research Objectives

1. To examine the role of adaptive logistics in enhancing supply chain resilience in the face of global and local disruptions.
2. To evaluate the key components and technologies enabling adaptive logistics strategies in modern supply chains.
3. To assess the current state of adaptive logistics practices among businesses operating in Sri Lanka.
4. To propose a framework or set of best practices for implementing adaptive logistics in vulnerable supply chain environments.

Research Questions

1. How does adaptive logistics contribute to building resilient supply chains amid volatility and disruption?
2. What technologies and capabilities are most critical to implementing adaptive logistics?
3. To what extent are Sri Lankan firms integrating adaptive logistics into their supply chain strategies?
4. What lessons can be drawn from successful adaptive logistics practices in Sri Lanka and beyond for application in other volatile markets?

Literature Review

1. Supply Chain Resilience and Volatility

Resilience of supply chains is the ability of a supply chain to foresee, adapt to, react to, and recover from unanticipated events while keeping ongoing operations and protection of customer service standards. Economic uncertainty, climatic change, political upheaval, and health crises like the COVID-19 epidemic have shown weaknesses in world supply networks in recent years, therefore stressing the requirement of resilience (Broadstock et al., 2021). Unexpected changes in demand, supply, and external risks including natural catastrophes, pandemics, and geopolitical conflicts cause volatility in supply chains. These hazards distort the flow of products and services, raise prices, and lower consumer satisfaction. The research acknowledges that conventional lean and just-in-time models are inadequate for handling excessive volatility, therefore a change towards more flexible, adaptive methods (Akkartal & Mızrak, 2023). Moreover, the management of crises and the maintenance of operations under duress depend critically on organisational culture and the integration of high dependability concepts (Cantu et al., 2020).

2. Defining Adaptive Logistics

Adaptive logistics is the technical and strategic ability of logistics systems to rapidly reorganise and react to changing supply and demand. Real-time data visibility, automation, distributed decision-making, flexible transportation and warehouse technologies all play part here. Adaptive logistics combines agility and responsiveness into supply chain operations (Karimian et al., 2022), unlike conventional logistics, which sometimes depends on set paths, inventory levels, and timeframes. It improves fast disturbance detection, alternative evaluation, and minimal delay change implementation ability (Dohale et al., 2022). Particularly in sectors including perishable food and textile supply chains during the COVID-19 epidemic, the acceptance of digital technologies including artificial intelligence (AI), blockchain, and the Internet of Things (IoT) has further accelerated the effectiveness of adaptive logistics strategies (Kumar et al., 2021).

3. Enablers of Adaptive Logistics

Integration of modern technology, flexible infrastructure, data-driven decision-making, and cooperative networks is key enabler of adaptive logistics. While artificial intelligence (AI) provides dynamic route optimisation and demand forecasting to increase responsiveness, the Internet of Things (IoT) lets real-time tracking of assets, so boosting visibility across the supply chain (Norrman & Wieland, 2020). By improving openness and confidence in logistics transactions, blockchain technology guarantees safe and traceable exchanges and is therefore very important (Cole, Stevenson & Aitken, 2019; Ejairu et al., 2024). Modular warehouses, transportable logistics hubs, and dynamic fleet management among other flexible infrastructure offer the agility required to react quickly to unanticipated occurrences. Real-time data analytics also helps companies to identify early on interruptions and distribute resources to minimise harm. Synchronised decision-making and effective recovery during crises depend also on cooperative networks among distributors, suppliers, and third- party logistics providers (Norrman & Wieland, 2020).

4. Adaptive Logistics in Crisis Response

Humanitarian logistics and disaster response depend much on adaptive logistics. During the COVID-19 epidemic, for example, supply chains that rapidly rearranged their sourcing, routing, and delivery systems responded better to demand surges and shortages (Kumar et al., 2021). Adaptive logistics techniques include mobile logistics systems, pop-up warehouses, and local sourcing have been used by humanitarian organisations as the World Food Program and the Red Cross to boost agility in disaster-torn areas. Furthermore noted as essential for increasing adaptive ability during crises are public-private cooperation. Governments significantly influence logistical responsiveness by removing legal restrictions, offering financial support, and funding infrastructure improvements (Mancini, De Camillis & Pennington, 2013; Huang, Uppal & Shi, 2002).

5. Adaptive Logistics in the Sri Lankan Context

Natural catastrophes, political unrest, port congestion, and legal obstacles all provide difficulties for Sri Lanka's logistics industry. Still, new projects by the government and business sector point to an increasing curiosity about adaptable logistics. Early adoption of adaptable methods may be seen, for instance, in the integration of mobile warehouses during post-disaster recovery and the usage of blockchain for traceability in export-oriented industries such tea and textiles (Sugathadasa, Perera & Liyanage, 2020). Still, the use of adaptive logistics is scattered and mostly limited to international companies. Many times lacking the financial and technological capacity to make investments in modern logistics systems, small and medium businesses (SMEs) are Given research indicates Sri Lanka's supply chain risk management techniques are still developing, this disparity emphasises the requirement of scalable and easily available adaptive logistics models catered to local conditions (Athalanka, 2019).

Research Methodology

1. Research Design

This study uses a qualitative methodology to investigate how adaptive logistics could help to create strong supply chains especially in uncertain economic times. This study is suited for qualitative research as it lets one have a thorough awareness of the complexity, difficulties, and solutions related with adaptive logistics. The main techniques of data collecting for the study will be expert interviews and case studies.

2. Data Collection Methods

The primary data collection methods will include:

a. **Expert Interviews**. Industry professionals including supply chain managers, logistics coordinators, and university researchers will be semi-structuredly interviewed. In the framework of worldwide supply chains, these interviews will offer insightful analysis of present methods, difficulties, and success stories of adaptive logistics. An interview guide will be used for the interviews, including open-ended questions meant to probe the participants' viewpoints on adaptive logistics techniques.

b. **Case Studies**. Two case studies from local and worldwide businesses using adaptive logistics will be examined to show the useful use of these techniques. These case studies will be chosen depending on their applicability to the goals of the research and their established knowledge with adaptive logistics in volatile surroundings. Secondary data from business reports, industry periodicals, and other pertinent sources will be used in analysis of the instances.

3. Sampling

A purposive sample method will be applied to choose participants for expert interviews with particular expertise or experience connected to supply chain resilience and logistics. Ten to fifteen people from a range of businesses including manufacturing, retail, and logistical services will make up the sample to guarantee a wide spectrum of ideas. The participants will be chosen according on their experience, professional positions, and knowledge in adaptive logistics. Companies displaying creative or effective use of adaptive logistics will be selected for the case studies. The firms will be chosen depending on elements like:

a. Proven ability to maintain supply chain resilience during disruptions.

b. Use of advanced technologies (e.g., AI, blockchain, IoT) in logistics.

c. Relevance of their operations to global and local market conditions.

4. Data Analysis

Thematic analysis will help to examine the material gathered from case studies and expert interviews. This approach searches the data for, analyses, and reports themes—that is, patterns. The methodical approach of the research procedure will guarantee accurate and significant study of the interview material. All interviews will first be videotaped and transcribed in order to keep great accuracy in recording the answers. After the data is transcribed, it will go through a classification process whereby important themes and categories including adaptive logistics methods, resilience, obstacles, and best practices will be found. This coding system will provide a data organisation under control. The coded data will next be arranged into more general themes fit for the study goals. At last, these issues will be seen in view in light of current research, making links between the results and the larger framework of adaptive logistics. The interpretation will result in findings on the function of adaptive logistics in improving the resilience of supply chains, therefore providing insights that support both scholarly knowledge and useful recommendations for companies.

5. Ethical Considerations

Fundamental to this research are ethical issues that guarantee participants' rights and privacy are safeguarded all during the study. All interview participants will provide informed consent, which will be fully enlightened on the goal and extent of the research under the promise that their participation is voluntary and that they may stop at any point without consequences. Strict maintenance of confidentiality will be followed; all personal identification will be eliminated to anonymise participant answers for the final report. Strong data security policies will also be followed to safeguard all research tools, including transcripts and interview recordings, which will be safely kept and available just to the study team.

6. Limitations

This study approach has several restrictions even if it is meant to provide insightful analysis of adaptive logistics. Given the qualitative character of the research, the results might not be generally relevant across all sectors or supply chains especially those running in diverse economic circumstances. Furthermore, the somewhat limited sample size of case studies and expert interviews might restrict the variety of points of view and therefore narrow the whole scope of the research. The case studies' dependence on secondary data might potentially limit the depth of investigation in some areas as it could not include the most recent or thorough information. Notwithstanding these constraints, the selected approach still fits very nicely for offering a sophisticated and in-depth knowledge of adaptive logistics in turbulent supply chain situations.

Conclusion

Emphasizing risk management and crisis response techniques, this research article explores the function of adaptive logistics in creating robust supply chains among local and worldwide market variations. Businesses have to modify their supply chain strategies to guarantee continuity, reduce disturbance, and preserve operational efficiency in the face of an ever changing global market. Therefore, reducing the effect of unanticipated occurrences such political unrest, natural disasters, and economic downturns requires a knowledge of how adaptive logistics techniques support supply chain resilience. Using case studies and expert interviews, the study takes a qualitative tack. While case studies look at actual companies that have effectively adopted adaptive logistics solutions, expert interviews offer insights from business leaders like supply chain managers and logistics coordinators.Both data sources provide a thorough grasp of adaptive logistics methods and how they affect resilience.

The results of the study will add to the body of knowledge already in use on supply chain management by stressing efficient adaptive logistics solutions and the best practices that have shown effectiveness during crises. It will also discuss the difficulties companies have preserving logistical resilience and offer doable suggestions for getting beyond these difficulties. Specifically, the study focusses on the experiences of Sri Lankan businesses where distinct local issues and market situations may give insightful analysis of the worldwide usage of adaptive logistics. By including more flexible, adaptable, and robust logistics systems that can resist the constraints of a turbulent global economy, the ultimate results of this research can help organizations better plan for future uncertainty.

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THE ROLE OF ADAPTIVE LOGISTICS TOWARDS THE RISK MANAGEMENT

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Abstract

This study explores the significance of using adaptive logistics concepts towards risk management. Usually, the logistics systems employ under the condition of uncertainty, random processes. Further, nowadays, since the market and business environment has become more and more complex, undesirable disruptions occur in logistics processes and may result in weakening organizations' strengths and performances. So, the aim of this study is to provide a wide vision of improving the adaptability of logistics management to mitigate the risk or managing the risk involved in the logistics processes.

Key Words: Adaptive logistics, risk management, logistics processes

Introduction

Logistics can be defined as a process of linking activities of the manufacturers from buying raw materials to the final products to it's customers. The Journal of Logistics Managements (1998) defined logistics is the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements.

At the beginning, logistics is described as managing physical delivery and storage in an efficient way to meet the organizational requirement. But the evolution of concepts of productivity and ideologies of market competition forced the changes in the field of logistics management. Therefore, Logistics management in effective and efficient ways has become a business strategy in business' long term development plans. According to the council of supply chain management professions, logistics management should aim to achieve seven rights, which include delivery the right product to the right place at the right time with right quantity and right quality, and at the right price to the right customer.

Further, Loutenço, H. R. (2005) identified the key to success in logistics management requires heavy emphasis on integration of activities, cooperation, coordination and information sharing throughout the entire supply chain, from suppliers to customers.

In today's global business environment, logistics systems are widely considered to be vulnerable and exposed to numerous threats (Xanthopoulos et al., 2012; Sodhi et al., 2012). Events such as accidents and political conflicts can disrupt markets, often leading to significant losses for supply chain participants (Tang, 2006; Xanthopoulos et al., 2012). High levels of uncertainty in both supply and demand contribute to increased operational risk within logistics networks (Lewis, 2003).

Natural disasters such as the 2004 Indian Ocean tsunami (Altay and Green, 2006) and the 2011 magnitude-9 earthquake in Japan, further challenge logistics operations and highlight the need for effective emergency response systems (Hua and Sheu, 2013; Sheu and Pan, 2014). Moreover, common business strategies like logistics outsourcing and strategic alliances introduce additional layers of risk to these systems (Choi et al., 2016).

In such a situation the importance of adaptive logistics can be discussed. Adaptive logistics can be simply defined as a data driven approach that allows organizations to optimize their supply chains in real times to quick response to the changing market conditions.

Incessant changes in information technology have greatly supported logistics management, particularly in data exchange and communication across the entire process flow. Technologies such as barcodes, RFID, point-of-sale systems, EDI, VPNs, and ERP systems not only help reduce the complexity of physical process flows but also lower the risk & uncertainty by enabling better information sharing among partners within the supply chain.

So that, this study focuses on a comprehensive exploration on the role of using adaptive logistics towards risk management.

Methodology

The researcher used the desk review method to review the international reports, handbooks, web-based published articles, published research papers and etc. Secondary data collected from these sources based on researcher's analysis and findings. Through a comprehensive review of existing literature available in research papers, web sites, journals and research papers, researcher has integrated the insights and perspectives related to the research objective.

Discussion and implications

According to the existing literature on adaptive logistics, the first use of the word of adaptive logistics‖ is began in the era of 2001-2002 with the evolution of new technologies in the field of information technology. Automating the supply chain networks using new technologies including agent-based, RFID and web services can be considered as the first step of adaptive supply chain (SAP 2002).

When evaluating ancient roots of the basic principles of logistics such as transportation, storage, resource management have been used for years and examples can be seen in early military operations. In the beginning of the 19th and 20th centuries, widening of mass manufacturing and industrial production caused the development and more efficient and organized systems in logistics. In the post-industrial era, it is witnessed that the emergence of global supply chains with increased.

Competition made the need for greater flexibility and agility in logistics. In such a situation and discussion, the concept of adaptive logistics gained more prominence place due to the organizations face more complex and frequent disruptions caused by the reasons as economic downturns, global climate changes pandemic situation in locally and globally and geopolitics events.

Key Components of Adaptive Logistics

Real time data analysis is one of the key components of adaptive logistics since it heavily relies on the on the data analysis. On the spot informed decisions can be taken by the organizations on the availability of real time data.

Since the organization designs their own logistic systems with the capability to prompt response changes in demand, supply chain disruptions, or changing market conditions, dynamic supply chain design also plays a vital role.

Another key prominent component of adaptive logistics is collaborative networks since adaptive logistics always encourage partnership and collaboration. If organizations form strong networks with supplies, stakeholders, distributors, throughout this network, the organization can achieve communication and coordination hence agile response to unforeseen events.

Integration of cutting - edge technologies like the Internet of Things (IoT), artificial intelligence, and automation have become fundamental aspects of adaptive logistics. These technologies optimize operations, enhance visibility, and enable predictive modeling to anticipate potential challenges.

Benefits of Adaptive Logistics

1. **Resilience**. Adaptive logistics builds resilient supply chains, ensuring companies can quickly recover from disruptions and continue operations with minimal downtime.

2. **Cost Efficiency**. By optimizing processes and minimizing disruptions, adaptive logistics helps re-duce operational costs, contributing to overall cost efficiency.

3. **Improved Customer Satisfaction**. Quick response to changes and uninterrupted service delivery enhance customer satisfaction, fostering loyalty and a positive brand perception.

4. **Sustainability**. The adaptability of logistic systems allows for more sustainable practices, as companies can adjust operations to align with environmentally friendly initiatives.

Adaptive logistics represents a paradigm shift in the world of logistics, addressing the need for flexibility and agility in an increasingly dynamic environment. As the world continues to evolve and face unexpected challenges, businesses must embrace and integrate adaptive logistics to ensure smooth operations and sustainable growth.

Risk Management

The first step in effective risk management is identifying the sources or drivers of potential risks to a particular organization. Disruptions can arise in numerous ways and at any time, so organizations must take a structured approach to recognize and assess all possible threats in advance. Risks can stem from both external environments and internal operations, but in logistics chains, external risks often pose a greater challenge. Companies must therefore manage all possible internal process disruptions while also monitoring risks associated with suppliers and customers.

However, the impact of a risk is not determined solely by where it originates. A key factor is the organization's vulnerability or weakness within specific processes, functions, or conditions. These vulnerabilities may remain hidden under normal circumstances but can significantly worsen the impact of a disruption.

For example, a company using lean production to reduce inventory costs may be more efficient under typical conditions, but this strategy can lead to serious shortages when unexpected events like natural disasters occur. Ultimately, even if multiple companies face the same risk, the outcomes will vary depending on each organization's unique vulnerabilities. Therefore, identifying the inherent risks to a particular organization is important.

The Role of Adaptive Logistics in Supply Chain Risk Management

Adaptive logistics, with its emphasis on dynamic networks and flexible strategies, plays a vital role in mitigating or managing risks across the supply chain process. By responding effectively to evolving market conditions and unexpected disruptions, adaptive logistics helps minimize the impact of these events such as natural disasters, supplier failures, and transportation delays.

Enhancing Agility is one of key components to adapting to the changing environment. Adaptive logistics systems are usually built to respond swiftly to changes. This real-time flexibility allows businesses to quickly reconfigure their supply chains in response to disruptions, reducing downtime and potential losses. Thereby, the application of adaptive logistic concept is enable the organization to achieve the agility.

With the data placing to a prominence place in the concept of adaptive logistics, supplier diversification can be done. A key component of adaptive logistics is diversifying supplier networks to avoid over-reliance on a single source. By having multiple suppliers in place, businesses can continue operations even if one supplier encounters issues, reducing the risk of complete supply chain breakdowns.

Adaptive logistics emphasizes a proactive approach to risk management. This includes identifying potential threats in advance and developing contingency plans, enabling businesses to be prepared and respond effectively before disruptions escalate. By using scenario planning, companies that implement adaptive logistics can anticipate a variety of potential disruptions and develop tailored response strategies for each. This proactive approach enhances resilience and ensures they are well-prepared to handle a wide spectrum of challenges.

Effective inventory management is another cornerstone of adaptive logistics. By optimizing inventory levels, businesses can balance the risks of overstocking and understocking, ensuring they remain responsive to changes in demand while avoiding costly supply chain interruptions.

Adaptive logistics frequently incorporates cutting-edge technologies to boost adaptability and efficiency. Tools such as real-time data tracking, automated systems, and advanced analytics enhance supply chain visibility, improve decision-making, and streamline operations.

An adaptive logistics framework enables businesses to redesign their supply chain networks dynamically. This may involve adding or removing facilities, rerouting shipments, or reallocating inventory based on current conditions, ensuring that the network remains aligned with business needs.

Transportation efficiency is also enhanced under adaptive logistics. With better route planning, real-time shipment tracking, and responsive logistics systems, businesses can reduce delays and maintain consistent delivery performance even during disruptions.

When discussing the way of using adaptive logistic concepts to a real world, it is understandable that standardized, real-time data feed from various functions, regions, and product lines across the organization is just the starting point. The ultimate objective is to build a fully connected, end-to-end, and collaborative supply chain, one that includes upstream suppliers and downstream sales channels, all sharing shipment-specific location and status data via devices like sensors, scanners, and transmitters, along with contextual information such as traffic, weather, and location from third-party sources.

Advanced algorithms and digital simulations then process this mix of real-time and historical data, transforming it into actionable insights aligned with the organization's strategic goals and business rules. This enables continuous monitoring of supply and demand signals, identification of potential bottlenecks, and implementation of corrective actions, all while optimizing workflows, assets, and personnel to improve efficiency and control costs.

To support quick and effective decision-making, user-friendly, customizable dashboards present complex data in clear, visually digestible formats, enhancing both operational awareness and internal communication.

New technology solutions have prompted a rethinking of conventional business processes, with new approaches to solve intransigent problems. In transportation, for example, that might mean:

1. Outsourcing to 3PLs where fulfillment cost and risk no longer justify an added degree of control. With the right operating footprint, performance record, and niche expertise, shippers can negotiate an optimal balance of unit price and volume commitment to maintain seasonal and cyclical flexibility.

2. Networked shipper-carrier platforms to balance lanes and match loads, either as return TL freight or tendered as LTL cargo to fill a trailer or container outside a regular carrier's service area or schedule.

3. Formalized space-sharing arrangements with carriers or other shippers moving freight on compatible routes and schedules to optimize asset utilization while reducing operating costs as well as trips and related fuel consumption and emissions.

In warehousing, companies are turning to solutions such as:

1. Process automation that digitizes and automates standard, recurring back-office forms and processes that are often tasked to employees with other responsibilities as supplemental work no one wants to do. Automation speeds those processes, reduces errors, and frees up staff for more productive work.

2. Automated identification and data collection (AIDC) that uses bar codes, RFID, or speech recognition to prioritize and assign work, and to measure performance.

3. Leased mobile robotic systems like automated mobile robots (AMRs) or goods-to-person (G2P) shelving systems—to enhance the speed, accuracy, and productivity of a fixed human workforce by reducing travel time in the pick, pack, and replenish functions; less travel time means less repetitive stress, more regular hours, and less workforce churn.

4. Micro-fulfillment centers in reconfigured physical store space, as a low-cost alternative to leasing or outsourcing last-mile capacity in high-density areas, bringing product closer to customers.

5. Shared complementary warehouse capacity, a growing trend as companies recalibrate their warehouse networks to reach desirable customers and as warehouse operators look for seasonality, route, product, or other commonalities to maximize downtime asset utilization.

When analyzing the question of how an adaptive logistics approach might help organizations across different sectors add comprehensive agility and resilience for better risk management within the organizations, it is obvious that a lifestyle products retailer faced challenges from product lead times in aligning planning and buying strategies, collaborating with partners on timing and quantity of materials purchases, and managing exceptions. Digital integration among customers and suppliers improves transparency and synchronizes end-to-end planning; and AI-enabled analytics optimize the timing of sourcing and production steps to meet delivery commitments; and collaboration and visualization tools make data instantly actionable, accessible, and shareable.

Optimization efficiency is a key component when a maker of building aggregates with a complex production and distribution network, pursuing a net-zero strategy, needed to plan more precisely against fluctuating demand, volatile raw materials and energy costs, and unexpected equipment breakdowns. Advanced analytics of the organization may help to support decision-making to optimize the supply model, manufacturing footprint, plant, and equipment capacity utilization; assess make-buy sourcing options; and monitor operations to make predictive maintenance and repair recommendations.

Fleet management is also another vital factor when Operators of truck fleets, whether private, truckload/LTL, or 3PL, manage complex networks with many variables, from traffic and weather to fuel costs to workforce attrition to environmental and safety regulation.

Conclusion

Adaptive logistics isn't a plug-and-play solution, it's a dynamic, multi-phase, data-driven approach. It begins by creating visibility into operations and performance, then uses that insight to optimize, automate, and coordinate people and resources across the organization. From there, it extends outward to foster strategic, collaborative partnerships that support mutual growth and competitive advantage.

The first step is developing a deep understanding of the customer base by segment, along with the broader macroeconomic factors influencing demand. That same level of insight must then be applied upstream to the supply base to build a comprehensive end-to-end market intelligence system, one that can identify emerging shifts and anticipate future trends and thereby deeply support mitigating and managing the possible internal risks.

From this intelligence, adaptive flexibility evolves. It enables organizations to integrate the right blend of process improvements, organizational capabilities, and technologies ensuring the agility to align people and assets with changing demands and consistently maintain optimal performance at scale and it make the organization excel in risk management.

Adaptive logistics may not be handled by those disruptions along itself through only making systems, but the future resilience of the organizations can be strengthened by learning from the disruptions and adapting the structure and processes.

Furthermore, in a world driven by information and connectivity, the field of adaptive logistics also has risen to a new level with the integration of cutting-edge technologies. From applying artificial intelligence algorithms to utilizing IoT (Internet of Things) devices for real-time monitoring, these innovations are transforming the concept of logistics into a highly adaptable and agile discipline. Adaptive logistics emerges as an essential approach in this context, enabling organizations to swiftly adjust to changing demands and optimize their performance in this dynamic global landscape.

In such a vibrant world, adaptive logistics concepts are considered as a prominent tool to ensure the resilience and smoothness of business operations thereby for sustainable risk management strategies. Therefore. Adaptive logistics cannot be considered as only a necessary response to uncertainties but also a smart investment towards a successful and steady business future.

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RISK MANAGEMENT AND CRISIS RESPONSE: BUILDING RESILIENCE TO GLOBAL AND LOCAL MARKET FLUCTUATIONS

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Abstract

In a more volatile global economy with geopolitical tensions, climate disruptions, and pandemics, supply chains are facing record risks that need to be addressed through aggressive risk management and crisis response. This article examines how organizations can attain resilience to global and domestic market volatility through adaptive logistics, synthesizing academic literature and industry experiences. Strategic responses involve diversification of suppliers to counter dependency risk, technology integration (AI, IoT, blockchain) for improved visibility and predictability, and strategic inventory management to balance lean with buffer stocks. Collaborative networks and agile processes also allow for quick adjustment to disruptions, as seen in Toyota's earthquake recovery after 2011 and Pfizer's blockchain-based COVID-19 vaccine delivery. Organizational culture's contribution prioritizing continuous learning, risk-based decision-making, and post-crisis review is vital to the anchoring of resilience. Case studies and models emphasize forward-looking planning, incorporating sustainability, and adherence to regulation as critical elements in the management of future uncertainties. By an integrated strategy of uniting operational flexibility, technological breakthrough, and collaboration with stakeholders, firms can convert vulnerabilities into a source of competitiveness, ensuring business continuity in an uncertain and fragmented world.

Key Words: Technology integration, COVID-19 pandemic, global economy

Introduction

In the era marked by geopolitical tensions, economic volatility, and climate-related shocks, supply chains face new challenge. The COVID-19 pandemic, chip shortages, and the Suez Canal blockage all demonstrate how localized disturbance can balloon into global crises. For businesses, the ability to manage risk and respond to crises is no longer solution, it is a strategic important. Adaptive logistics, focusing on flexibility, real-time responsiveness, and technological integration, has become the foundation for the development of resilient supply chains that can weather market volatility. This essay discusses how organizations can utilize risk management frameworks and crisis response mechanisms to strengthen their supply chains from global as well as local disruptions. Through synthesizing insights from research literature and industry best practice, this discussion demonstrates the importance of resilience in ensuring continuity of operations and competitiveness.

Understanding Market Fluctuations and Their Impacts

Global and local sources of market volatility intersect. Global threats disrupt cross-border supply chains, such as trade wars, currency fluctuations, and pandemics. Domestic threats labor unrest, regional regulatory shifts, and natural disasters shut down production centers. The 2021 pandemic-level Suez Canal shutdown locked up $9.6 billion in daily trade, for instance, to illustrate how current single-point vulnerabilities in global networks increase system-level vulnerabilities (UNCTAD, 2021). Likewise, the U.S.-China trade war affected electronics and automotive industries because of tariff increases, which compelled companies to re-evaluate supplier reliance (Bown, 2019). The interconnected nature of modern supply chains means that disruptions in one node ripple through the network. For example, the 2011 floods in Thailand disrupted hard drive production, affecting tech firms across the globe that relied on just-in- time inventory systems (Sheffi, 2015). Such events highlight the need for resilience, or the capacity to "anticipate, prepare for, respond to, and recover from disruptions" (Christopher & Peck, 2004).

Understanding Risks in Global and Local Markets

Supply chain hazards originate from sources that are varied and often intersect unexpectedly. These main categories are:

1. **Economic Risks**. Inflation, demand unpredictability, and currency volatility. Economic risks are some of the most widespread and interdependent supply chain challenges in the current volatile global economy. Economic risks are spawned by macroeconomic uncertainty, instability in financial markets, and regional economic instability, all of which have the potential to derail production chains, increase costs, and lower profitability. For example, the 2008 financial crisis disrupted credit flows, forcing firms to reconsider lean inventory models (Chopra & Meindl, 2016). In the following sections, we explore prominent economic risks and the resulting ripple effects on global and regional supply chains.

   a. **Currency Fluctuations**. Exchange rate volatility directly impacts cross-border trade costs, profit margins, and pricing strategies.

   b. **Inflation and Cost Volatility**. Rising input costs driven by energy prices, labor wages, or raw materials erode profitability and destabilize budgets.

   c. **Demand Volatility**. Economic downturns or abrupt shifts in consumer behavior can lead to overstocking or shortages.

   d. **Interest Rate Hikes and Credit Constraints**. Central bank policies directly influence supply chain financing.

e. **Trade Policy Shifts**. Tariffs, sanctions, and trade agreements reshape sourcing and distribution networks.

2. **Geopolitical Risks**. Political unrest, sanctions, and trade wars. Geopolitical risks are associated with political decisions, wars, or regulatory changes that disrupt investment, trade, or supply chain operations. These risks are often interconnected, unexpected, and capable of causing cascading disruption. The trade war between the U.S. and China impacted electronics and auto sectors, prompting firms to diversify suppliers (Bown, 2019). Below, we outline some significant geopolitical risks and their impacts on global and domestic markets

a. **Trade Wars and Tariffs**. Government-imposed tariffs, import/export restrictions, or trade barriers aimed at protecting domestic industries or retaliating against other nations.

b. **Sanctions and Embargoes**. Government restrictions on trade with specific countries, entities, or individuals, often for political reasons.

c. **Political Instability and Civil Unrest**. Government collapses, coups, protests, or civil wars that disrupt local operations.

d. Regulatory and Policy Shifts: Sudden changes in laws, taxes, or environmental regulations.

e. **Territorial Disputes and Military Conflicts**. Conflicts over borders, resources, or maritime routes that disrupt logistics.

f. **Cybersecurity Threats with Geopolitical Motives**. State-sponsored cyberattacks targeting critical infrastructure or supply chain data.

3. **Environmental Risks**. Natural disasters and climate change. Environmental hazards natural catastrophes (wildfires, floods), climate change (droughts, sea level rise), and resource degradation (water scarcity, mineral exhaustion) disrupt supply chains globally. Local events (e.g., Canada's 2023 wildfires) cascade into global delays, while systemic hazards like biodiversity loss jeopardize industries. Policy shifts (e.g., EU carbon taxes) raise compliance costs. Mitigation entails diversifying suppliers, employing renewables (e.g., solar energy), predictive analytics for disaster preparedness, and circular strategies (e.g., recycling). Preemptive strategies enhance resilience and align with ESG values, achieving long-term competitiveness. The floods in Thailand in 2011 halted 45% of the global hard drive supply, costing \$20–30 billion (World Bank, 2012).

4. **Technological Risks**. Cyberattacks and system crashes. Technological risks like cyberattacks (e.g., ransomware crippling logistics), system failures (e.g., cloud downtime stopping production), and obsolescence (e.g., AI rendering legacy systems obsolete) pose threats to supply chains worldwide and domestically. SMEs are exposed due to weak cybersecurity, while multinational corporations are at risk of data breaches (e.g., SolarWinds compromise) or IoT exposure (e.g., compromised smart factories). Mitigation necessitates strong cybersecurity protocols, ongoing tech updates, and employee training. Proactive implementation of blockchain for transparency or AI-powered predictive maintenance improves resilience in the face of emerging digital threats. Maersk's 2017 NotPetya ransomware attack cost the company over $300 million in downtime (Greenberg, 2018).

Localized risks such as labour strikes or local regulatory change complement international concerns. For instance, Brexit imposed customs issues, reducing UK-EU exports by 68% in early 2021 (Institute for Government, 2021).

Risk Management Strategies for Resilient Supply Chains

Critical tactics involve supplier diversification, using AI/blockchain for real-time transparency, strategic inventory buffers, encouraging collaborative networks, and building agile processes. Scenario planning early on, sound cybersecurity, and regular review of risk provide flexibility in the face of disruption. Building a risk-aware culture and investing in sustainability contribute still further to longer- term resilience.

1. Supplier Diversification and Localized Sourcing

Overdependence on one region or supplier increases vulnerability. Diversification sourcing from multiple geographies reduces dependence and provides insulation against localized shocks. For example, after the 2011 Tōhoku earthquake, Toyota diversified suppliers, reducing production downtime in subsequent crises (Sheffi, 2015). Similarly, with COVID-19, companies that had nearshoring or regional suppliers rode out port delays more easily than those that relied on transcontinental supply chains (McKinsey, 2020).

Challenges: Diversification creates issues of coordination cost and quality control. However, digital platforms like SAP Ariba enable tracking of supplier performance in real time, attaining flexibility versus control (Dubey et al., 2013).

2. Technology Integration: AI, IoT, and Blockchain

Emerging technologies increase accuracy and predictive abilities:

a. **AI and Predictive Analytics**. Machine learning algorithms forecast demand shifts and identify bottlenecks. For instance, Shell's AI-driven supply chain platform reduced data errors by 80%, improving crisis response (PMI, 2023).

b. **IoT Sensors**. Real-time monitoring of shipments and warehouse conditions. Maersk uses IoT-connected containers to monitor perishable goods, reducing spoilage by 20% (Wieland & Wallenburg, 2013).

c. **Blockchain**. Advances transparency in multi-stage supply chains. Walmart's blockchain system traces food origins in seconds, rather than days, enhancing recall management (Kshetri, 2018).

d. **Challenges**. High implementation costs and skills mismatch hold back SMEs. Collaborative consortia, such as IBM Food Trust, offer scalable technology solutions to small firms (Li & Chen, 2022).

3. Strategic Inventory Management

Whereas lean inventories reduce expenses, buffer stocks protect from stockouts. Pharmaceutical companies with strategic inventories of active pharmaceutical ingredients during COVID-19 prevented production stoppages (Govindan et al., 2015). Strategies such as dynamic safety stock setting buffers according to risk analysis trade off resilience for efficiency.

Challenges: Overstocking locks up capital. Software such as ToolsGroup's SO99+ streamlines inventories based on probabilistic forecasting, matching stock to risk appetite (Holweg et al., 2018).

4. Collaborative Networks and Public-Private Partnerships

Resilience needs to be a collective effort. In the 2020 PPE shortage, firms such as Ford and 3M worked together with governments to ramp up production, demonstrating tri- sector partnership strength (Roehrich et al., 2014). In the same vein, Toyota's Supplier Mutual Aid Program promotes resource-sharing among collaborators in times of disruption (Asano, 2012).

Challenges: Incentives misalignment and reluctance to share data hamper collaboration. Blockchain-supported platforms such as Trade Lens create trust by facilitating the secure exchange of data among stakeholders (IBM, 2021).

5. Agile and Flexible Processes

Agility the ability to change direction on a dime is key. Zara's rapid-fashion business, supported by localized production hubs, facilitates rapid redesigns in response to changes in demand (Christopher & Peck, 2004). Unilever redirected shipments by rail during the Ukraine war to bypass Black Sea disruption, illustrating logistical agility (Financial Times, 2022).

Challenges: Agility necessitates cultural change. Companies such as Amazon give decision-making power to frontline teams, eliminating bureaucratic lag (Harvard Business Review, 2020).

Organizational Culture and Continuous Improvement

Organizational culture and continuous improvement are also at the root of establishing and maintaining supply chain resilience. A culture of risk awareness emphasizes proactive vulnerability identification, open communication, and shared accountability. For example, corporations such as Cisco ritualize post-crisis assessments to examine disruptions, incorporating lessons into future strategies (e.g., post-2011 Japan earthquake audits). All employees are empowered to identify and report risks via mechanisms such as Nestlé's "Speak Up" system, promoting transparency.

Iterative process improvement using tools like PDCA (Plan-Do-Check-Act) or Six Sigma is continuous improvement. Toyota's "kaizen" strategy small, incremental improvements allows for rapid reaction to market changes. Training exercises (e.g., Pfizer's risk simulation exercises) and real-time monitoring of KPIs (e.g., recovery time, supplier performance) ensure responsiveness. Leaders must demonstrate resilience through investments in innovation (e.g., digital twins for scenario testing) and sustainability (e.g., Patagonia's sustainable sourcing).

Challenges in Organizational Culture and Continuous Improvement

Developing a strong organizational culture and sustaining continuous improvement are faced with multi-dimensional obstacles. Resistance to change derails innovation as employees cling to traditional processes. Misaligned leadership prioritizes short-term returns at the expense of long-term resilience, under-investing in critical initiatives. Departmental silos stifle cross-functional collaboration, delaying risk response. Post-crisis complacency leads firms to revert to traditional practices. SMEs face resource constraints, limiting access to state-of-the-art tools, while facing cultural misalignment of priorities in international teams. Measuring intangible outcomes (e.g., establishing trust) and preventing worker burnout from continual improvement is complex. Surmounting them requires concerted leadership, scalable solutions, and building a culture in which resilience is every one's job.

1. Resistance to Change

Resistance to change, driven by fear of the unknown or job insecurity, stalls innovation. Employees often reject new technologies due to mistrust or comfort with routines. This perpetuates inefficiencies, like outdated inventory systems. Mitigation requires transparent communication, pilot programs to showcase benefits and incentives for buy-in.

2. Leadership Misalignment

Leadership misalignment occurs when executives prioritize short-term profitability over long-term resilience, underinvesting in initiatives like cybersecurity or supplier diversification. Mitigation includes linking leadership bonuses to resilience metrics strategic alignment (Kotter, 2012).

3. Siloed Workflows

Siloed processes are where different departments operate independently, and risk responses are slow. R&D developed a vaccine for a pharma company but did not communicate with logistics regarding cold-chain needs, and it was spoiled (McKinsey, 2021). Mitigation requires integrated platforms for real-time data sharing and cross- functional coordination (Forrester, 2023).

4. Post-Crisis Complacency

Post-crisis complacency happens when companies return to pre-crisis habits after a disruption, believing that future risks are minimal. Post-COVID, 60% of SMEs lowered inventory buffers, making them susceptible to 2022 port strikes (McKinsey, 2022). Mitigation includes quarterly stress testing to ensure readiness (Gartner, 2023).

5. Resource Constraints

SMEs do not typically have budgets for advanced equipment or training. An apparel manufacturer delayed response to a warehouse fire due to inordinately costly sensors (Deloitte, 2022). Mitigation includes low-cost steps and government grants to digitally adopt (World Bank, 2023).

6. Cultural Misalignment in Global Teams

Cultural mismatch is present when regional priorities compete Southeast Asian suppliers' regional traditions were challenged by the stringent ESG standards of a multinational, which caused delays (Harvard Business Review, 2022). Remediation involves collaborative development of region-specific templates together with local actors to align global standards with regional realities (McKinsey, 2023).

7. Tapping Intangible Outcomes

It is difficult to measure cultural programs One firm canceled $500K training due to ROI being undefined (MIT Sloan, 2021). Fixes track high-level indicators like employee engagement on risk reporting or reduced near-miss occurrences (Gartner, 2023).

8. Employee Burnout

Continuous improvement demands overwhelm staff. A logistics firm saw 30% turnover in 2023 from unsustainable agility drives (Gallup, 2023). Mitigation balances innovation with well-being programs

9. Inconsistent Communication

Poorly executed cascaded protocols create confusion. One bank's unclear cyberattack procedures added to customer delays in 2023 (Forrester, 2023). Centralized tools and role-based playbooks are solutions.

Future Developments and Sustainability

New trends focus on sustainability as a pillar of resilience. Circular economy strategies, like recycling and remanufacturing, decrease the reliance on raw materials. Unilever's "zero waste" factories, for example, save costs while supporting ESG objectives (Seuring & Müller, 2008). Moreover, AI- powered digital twins model supply chain disruptions, allowing for preemptive changes (Ivanov & Dolgui, 2020).

Conclusion and Future Directions

Constructing agile supply chains entails an integrated approach embracing proactive risk management, technological innovation, and adaptive organizational cultures. Case studies of Toyota's recovery from disaster and Pfizer's vaccine rollout show that resilience rests on foundations like supplier diversification, artificial intelligence-driven analytics, and collaborative networks. Yet, the changing risk environment marked by climate change, geopolitical fragmentation, and cyber-attacks necessitates ongoing adaptation.

Looking forward, AI-led scenario planning would become central. Digital twins, virtual copies of supply chains, will allow companies to model disruptions such as pandemics or trade wars, stress-testing responses in real-time (Ivanov et al., 2020). Amazon's cloud-based simulations, for example, already optimize warehouse designs for flood resistance. Sustainability integration will become a necessity rather than a choice, propelled by regulations such as the EU's Carbon Border Adjustment Mechanism (CBAM) and consumer pressure. Businesses such as H&M are adopting circular economy approaches recycling clothing into new items and simultaneously mitigating risks associated with reliance on fluctuating raw material markets (Ellen MacArthur Foundation, 2022).

Regulatory change will also shape resilience. ESG adherence will pre-empt legal threat and stakeholder trust. Apple's Supplier Clean Energy Program imposing carbon-neutral production, for example, future-proofs against climate legislation (Apple, 2023). Further, collaborative ecosystems will expand, with public-private partnerships addressing systemic threats. The COVID-19 Vaccine Global Access (COVAX) program exemplifies how shared resources can democratize crisis solutions (WHO, 2021).

Emerging technologies like blockchain and IoT sensors will bring greater transparency and real- time tracking of ESG initiatives. Success, nevertheless, will depend on building agile cultures that emphasize continuous learning and employee well-being. Those firms that institutionalize resilience at the leadership alignment level, decentralized decision-making, and iterative learning will not only survive disruptions but thrive in sustainability and innovation. As Yossi Sheffi remarks, "Resilience is the new competitive advantage," and organizations that adhere to this philosophy will thrive in a world of boundless uncertainty.

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RISK MANAGEMENT AND CRISIS RESPONSE

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Abstract

Supply networks are now more exposed than ever to growing global risks including pandemics, geopolitical conflicts, disruptions from the climate, and economic volatility. Building resilient supply chains requires adaptive logistics, which is supported by strong risk management and efficient crisis response procedures. The frameworks, tactics, and technologies that businesses can use to foresee, lessen, and recover from supply chain disruptions are examined in this article. The paper offers insights and best practices specific to the logistics industry, with an emphasis on proactive risk assessment, integrated planning, real-time data utilization, and collaboration. The theoretical and practical underpinnings of adaptive logistics in crisis situations are reinforced by case studies and academic references.

Key Words: Risk management, supply chain disruptions

Introduction

The stability of supply chains is being impacted by the quick and frequently unexpected changes occurring in the global economy. Events like the Suez Canal blockade, the Russia-Ukraine conflict, and the COVID-19 pandemic highlight how important it is to have robust and flexible supply chain models. As the foundation of supply chains, logistics needs to change to include agile crisis response skills and dynamic risk management.

The supply chains of today are more integrated and global than ever. Although interconnectedness improves efficiency and market accessibility, it also makes people more open to upheaval. A failure or disruption in one region of the world can have repercussions in other regions and industries. Organizations must quickly move from conventional, linear logistics models to more flexible, intelligent, and adaptive systems if they want to stay competitive and responsive.

Understanding Supply Chain Risks

Supply chain risks can be categorized into internal and external threats:

1. **Internal risks**. Include personnel interruptions, technological malfunctions, quality problems, and operational failures. These come up in the organization's own or its close partners'procedures. Machine failures, order fulfilment mistakes, and staff shortages brought on by strikes or internal strife are a few examples.

2. **External risks**. Include pandemics, natural catastrophes, regulatory changes, cyber- attacks and geopolitical upheaval. Although these dangers are frequently beyond our control, they can be foreseen and reduced with careful planning. For instance, the flow of products across borders may be impacted by changes to import-export laws in one nation.

Furthermore, according to risk theorist Donald Rumsfeld's taxonomy, risks can be divided into three categories: known-knowns, known-unknowns, and unknown-unknowns. While unknown- unknowns, like black swan events, present the greatest risks because of their significance and unpredictability, known-knowns are simpler to prepare for.

Frameworks for Risk Management

Several frameworks guide the assessment and mitigation of supply chain risks:

1. **ISO 31000**. Offers concepts and recommendations for efficient risk management. It places a strong emphasis on integration into organizational procedures, leadership commitment, and a methodical approach to risk assessment, identification, and management.

2. **Supply Chain Operations Reference (SCOR) Model.** Combines risk identification and mitigation procedures with performance measures. Organizations can use the SCOR model to map out procedures, assess performance, and apply best practices in the areas of planning, sourcing, making, delivering, and returning operations.

3. **Enterprise Risk Management (ERM)**. Integrates risk consciousness into decision making and organizational culture. ERM ensures that risk management is not a background function but is integrated throughout strategic planning and operational activities.

These frameworks encourage a proactive rather than reactive approach by offering an organized prism through which organizations may examine and manage their risk environments.

Adaptive Logistics: A Strategic Imperative

The ability of a logistics network to instantly and dynamically adapt to shifting circumstances is known as adaptive logistics. By combining data intelligence, predictive analytics, and collaborative ecosystems, it surpasses conventional supply chain agility. Important elements consist of:

1. **Digital Transformation**. Gaining real-time visibility and predictive insights through the use of IoT, AI, and big data analytics. Logistics managers can estimate demand, keep an eye on shipments, and react quickly to irregularities thanks to these technologies. AI-powered demand forecasting, for instance, might modify replenishment strategies in reaction to patterns in customer behavior.

2. **Agile Operations**. Businesses can quickly adjust to interruptions thanks to flexible warehousing, modular transportation networks, and dynamic rerouting. Rerouting is possible in reaction to port closures or traffic delays because to cloud-based transport management systems (TMS).

3. **Scenario Planning**. Using simulation and backup plans to get ready for several interruptions scenarios. Businesses can evaluate the effects of different situations, such supplier failure, port shutdowns, or currency changes, by using digital twins of their supply chains.

The supply chain is changed by adaptive logistics into a robust, perceptive, and responsive system that can prosper in an unpredictable environment.

Crisis Response Mechanisms

An effective crisis response strategy involves several interrelated components:

1. **Early Warning Systems**. Using data analytics and artificial intelligence to identify possible dangers. Predictive analytics, for example, can watch social unrest that may cause delivery delays or detect weather patterns that may impact transportation routes.

2. **Crisis Management Teams**. Multidisciplinary groups prepared to act quickly and forcefully. Experts in logistics, IT staff, communication professionals, and executives with the authority to make crucial choices in an emergency should be on these teams.

3. **Communication Protocols**. Unambiguous and open lines of communication with interested parties. Stakeholders require regular and regular updates during a crisis. This fosters confidence and makes it possible for supply chain reactions to be coordinated.

4. **Post-Crisis Evaluation**. Improving future readiness by learning from disruptions. A post- mortem examination of the performance of the supply chain during a crisis might reveal flaws and areas for development. Additionally, it aids in keeping the risk management playbook up to date.

Building Collaborative Resilience

It takes more than one to build resilience. Collaboration and partnerships throughout the supply chain improve resilience and risk-sharing:

1. **Diversification of suppliers lessens reliance on a single source**. Risks related to regional disruptions, including natural catastrophes or political upheaval, can be reduced by having a wide supplier base.

2. **Integrated Platforms**. These allow suppliers, logistics companies, and customers to share data in real time. Delays and misunderstandings are decreased by the safe and transparent data flow made possible by block chain technology and cloud-based systems.

3. **Public-Private Collaboration**. Industry and government alliances for disaster assistance and infrastructure. Public institutions can be extremely helpful in mobilizing resources and guaranteeing the continuity of critical supply networks during national or regional emergencies.

4. **Risk Pooling and Insurance**. To lessen financial exposure from disruptions, cooperative insurance methods and risk-sharing agreements are used.

Case Studies

1. **Maersk and Cyber Resilience**. The NotPetya cyber-attack crippled Maersk's operations in 2017. Maersk responded by implementing a zero-trust architecture and making significant investments in cyber security infrastructure. The significance of digital risk readiness in a logistics world that is becoming more interconnected is highlighted by this scenario.

2. **Walmart during Hurricane Katrina**. Walmart's decentralized decision-making, solid supplier relationships, and sophisticated data analytics were credited with helping the company swiftly replenish and deliver necessities after Hurricane Katrina in 2005. A quick and effective crisis reaction resulted from the corporation giving store managers the freedom to act independently.

3. **Toyota's Earthquake Response**. Following the 2011 earthquake and tsunami in Tohoku, Toyota launched a "resilient supply chain initiative"

that included dual sourcing tactics, safety stock improvements, and supplier mapping. Since then, these actions have helped Toyota bounce back from upcoming setbacks more quickly.

4. **Nestlé and Global Crisis Management**. Regional hubs with explicit escalation mechanisms are incorporated into Nestlé's global crisis management architecture. Their supply chain command centers keep an eye on world events, allowing for quick decision-making and real-time resource reallocation.

Challenges in Implementing Risk Management Strategies

1. **Cost Implications**. Upfront investments in infrastructure, training, and technology are necessary to build resilient systems. The expense of establishing several supplier relationships or implementing cutting-edge technologies may be prohibitive for small and medium-sized businesses (SMEs).

2. **Data Silos**. Real-time visibility may be hampered by a lack of integration across partners and departments. Organizations run the danger of making decisions based on inaccurate or out of-date information if they don't have a unified data architecture.

3. **Opposition to Change**. The adoption of new systems may be hampered by organizational inertia and a lack of a risk culture. Involving leadership is crucial, as is cultivating an innovative and proactive mindset.

4. **Over-Reliance on International Supply Chains**. Although globalization has advantages, it also makes people more vulnerable to shocks from around the world. Resilience can be increased by rebalancing supply chains to incorporate regional or local components.

Recommendations for Practitioners

1. **Institutionalize Risk Management**. Incorporate risk assessment into strategic and operational planning at all levels. This entails upgrading backup plans and performing frequent risk assessments.

2. **Invest in Digital Tools**. For improved visibility and control, use technology like block chain, AI forecasting, and real-time tracking.

3. **Promote an Agile Culture**. To react quickly to change, promote creativity, cross- training, and adaptable work procedures.

4. **Create Multi-Tier Supplier Risk Assessments**. Recognize the risk exposure of their partners and suppliers in addition to direct suppliers.

5. **Take Part in International Collaboration**. Exchange resources and information by joining public-private partnerships, industrial consortia, and international forums.

6. **Create Crisis Playbooks**. Create thorough crisis response guides with methods for recovery, escalation, and communication.

Conclusion

Supply chains must not only withstand disturbances but also adjust and prosper in a world characterized by volatility and interconnection. It is now essential, not optional, to incorporate responsive crisis frameworks and strategic risk management into adaptive logistics. Organizations may create supply chains that are competitive and robust by embracing digital change, encouraging teamwork, and keeping a proactive risk posture.

Businesses who are successful in this endeavor will benefit from increased market position, better operational efficiency, and increased stakeholder trust. Resilience will be a crucial differentiator as the logistics industry gets ready for the future, allowing businesses to continuously provide value even in the face of uncertainty.

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ENHANCING RISK-RESPONSIVE MILITARY LOGISTICS NETWORKS: A STRATEGIC FRAMEWORK FOR RESILIENCE AGAINST GLOBAL DISRUPTIONS AND LOCAL MARKET INSTABILITY

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Abstract

The strategic framework of resilience enhancement in military logistics networks responds to the most significant vulnerabilities identified in complex supply chains highlighted by global disruptions such as pandemics, natural disasters, and cyberattacks. In the face of such "contested logistics", where an adversary intentionally targets military supply chains, this framework for adaptive means secular structure which emphasizes pre-planned capabilities for responsiveness and responsiveness to the environmental conditions. Instead, principles of strategic integration, responsiveness and continuity, reinforced through an integrative perspective of supply chain dynamics in contemporary warfare. The framework tackles issues regarding the trade-off between efficiency and readiness as conventional just-in-time models give way to more resilient just-in-case tactics, while promoting enhanced cooperation among defense stakeholders and investments in infrastructure and cutting-edge technologies. In order to improve the operational efficacy and adaptability of the US military in addressing current and emerging challenges, military logistics strategies will be adjusted to take geopolitical risks and shifting international relations into consideration.

Key Words: Military logistics, resilience, warfare

Introduction

Being the foundation for the mobility, provision, and upkeep of military personnel, logistics is essential to military operations (Serrano et al., 2023). A number of factors, including climate change, a lack of skilled labor, natural disasters, and competition for market access, make military logistics more difficult in modern times (Cade, 1971; Insight, 2024; Insights, 2024). This scenario is growing even more complex with the rise of contested logistics, which is characterized as a setting in which adversaries deliberately aim to interfere with logistics operations, setting it apart from unexpected incidents or natural disruptions (Mapp, 2023; Insight, 2024; King, 2024).

Events like the COVID-19 pandemic, the Colonial Pipeline ransomware assault, and the blockage of the Suez Canal have brought attention to the growing unpredictability of global supply chains and revealed serious weaknesses in military logistics networks (Quora, 2024). In a combat situation, when enemies may use anti-access/area denial tactics to obstruct supply lines and further their operational objectives, such disruptions could have disastrous results (King, 2024; Quora, 2024). "We are in a race of logistics," as NATO Secretary General Jens Stoltenberg highlighted, highlighting how critical it is to improve the interoperability and resilience of logistical systems in order to successfully respond to emerging threats (Quora, 2024). According to the U.S. military's understanding of the contested logistics environment, a strategic framework that places a high priority on creating resilient supply chains that can continue to operate despite intentional disruptions is required. (Leidos, 2024)

To ensure that military forces can react quickly to changing threats while safeguarding vital supply lines, logistics planning must take these difficulties into account and include insights and tactics that strike a balance between efficiency and readiness. (Sander, 2024b)

Methodology

This study used a thorough desk research approach that was enhanced by a thorough literature review and an examination of current military logistics procedures. By obtaining pertinent data from published sources without engaging in original data collection, the desk research approach allowed for a comprehensive analysis of risk-responsive tactics in military supply chains. The study combined data on military logistics resilience and contested environments from defense publications, military doctrine manuals, academic journal articles, and strategic studies. Finding real-world applications and effective adaption techniques was made possible by case studies of military missions that encountered logistical difficulties. In order to gain knowledge on technology integration, teamwork, and just-in-case logistics models, the study also included an analysis of defense industry reports and strategic frameworks. Important background information on geopolitical issues and global security concerns impacting military logistics networks was supplied by government and NATO publications. This scientific approach made it easier to comprehend strategy frameworks for improving military logistics systems' resilience against local market volatility and global disruptions (Gupta, 2024).

Strategic Framework

Sustainability is a crucial component of a military strategy, according to the strategic framework for improving risk-responsive military logistics networks. The National Defense Industrial Strategy, which emphasizes the U.S. military's significant reliance on foreign countries, the shortcomings of the nation's workforce force, and the lack of insight into global logistics needs, serves as the foundation for this strategy (America, 2021; Mapp, 2023; Saraev, 2023)Improvements in the military's industrial base's breadth, depth, scope, and resilience are recommended by the plan to overcome these weaknesses (Insight, 2024)

1. Key Principles of Sustainment

Integration, foresight, responsiveness, simplicity, economy, survivability, continuity, and improvisation are the eight sustainability principles that form the basis of this paradigm. These guidelines help military organizations maintain operational effectiveness and data security while adjusting to the complexity of contemporary conflict [6]. A more traditional and reactive approach to supply chain management is required for military logistics, which are frequently restricted by stringent cybersecurity measures, in contrast to commercial sectors that have easily embraced cutting-edge technologies like IoT tracking and AI-driven diagnostics(Salisbury and Rowlands, 2024).

2. Challenges and Opportunities

Military logistics and procurement encounter particular difficulties, such as the intricacies of public bidding and multi-stakeholder supervision. Defense agencies must update supply chains while guaranteeing safe, domestic maintenance and support in order to get beyond these obstacles (Zachery, 2020; Sarah, 2025b). In order to effectively respond to disruptions and crises, flexibility and adaptability are made possible by the integration of just-in-time (JIT) and just-in-case (JIC) techniques (Sarah, 2025b).

3. Collaborative Efforts and Investment

The framework also emphasizes how crucial it is for defense stakeholders to work together under the direction of explicit instructions from national leadership. To anticipate future needs and possible scenarios, scenario-based planning and well-informed military judgment are essential (Rajesh, 2024). Building a robust defense supply chain that not only bolsters domestic capabilities but also fortifies ties with foreign partners requires investments in infrastructure, such as increased warehouse capacity and cybersecurity measures(Zachery, 2020; Mohammed, et al., 2023).

In order to ensure operational readiness in an increasingly complex security landscape, defense forces may more effectively anticipate and respond to local market fluctuations and worldwide interruptions by prioritizing resilience through a strategic framework that incorporates both contemporary supply chain procedures and traditional military imperatives (Rajesh, 2024; Torres, 2025).

Implementation Strategies

Enhancing risk-responsive military logistics networks requires effective implementation tactics, especially when dealing with local market uncertainty and global downturns. These tactics cover a variety of methods meant to increase operational effectiveness, supply chain resilience, and general military preparedness.

1. Building Redundant Supply Routes

The creation of redundant supply routes is one of the fundamental tactics for improving military logistics. This strategy guarantees that there are several routes for the movement of commodities, enabling supply chains to be flexible and dependable even in the face of interruptions. Military logistics can reduce the risks associated with single points of failure and ensure the flow of vital supplies by diversifying their supply channels (Sani, et al.,2022; Chau, 2025; Torres, 2025).

2. Leveraging Predictive Analytics

Another crucial tactic is to use predictive analytics. Military logistics can foresee possible interruptions and make well-informed decisions to reduce risks by examining data patterns and trends. Military planners can assess different situations and create strong contingency plans suited to particular operational requirements by using predictive models to assist scenario-based planning (Agency, 2024; Sarah, 2025a). Better readiness and resilience are eventually ensured by this proactive method, which enables speedier reactions to unanticipated occurrences.

3. Enhancing Cybersecurity Measures

Strong cybersecurity is crucial in the current digital era to safeguard logistics operations against online attacks. Increasing cybersecurity safeguards can help stop possible breaches that could interfere with operations as military supply chains become more and more reliant on technology. To find weaknesses in the logistics network, this entails making investments in safe communication systems, putting in place stringent access controls, and carrying out frequent security assessments (Dowd, et al.,2023; Sander, 2024a).

4. Adopting a Just-In-Case (JIC) Mindset

A major change in military logistics strategy is the adoption of a Just-In-Case (JIC) supply chain model. This strategy places a strong emphasis on being ready for unforeseen emergencies by keeping sufficient supplies in stock and making sure that the necessary resources, including skilled staff and equipment, are always available. Paul Lyall has pointed out that the emphasis needs to change from just monitoring inputs to making sure that outputs, such military preparedness and capability availability, are given priority (Heckmann, 2023; Rajesh, 2024). This tactic strengthens the military's capacity to react quickly to new threats.

5. Collaboration and Long-Term Investments

The military and industrial partners must work together to successfully implement these plans. A more robust supply chain may result from stakeholders, like the Ministry of Defense, sharing commercial risks. In order to sustain military logistical needs over time, long-term investments in infrastructure improvements like expanded warehousing capacity and improved supply chain technologies are also essential (Insights, 2024; Sander, 2024a). In addition to ensuring that the military continues to be a reliable ally on the international scene, this cooperative effort can enhance domestic capabilities.

6. Adapting to Dynamic Environments

Finally, military logistics must continue to be flexible under changing conditions. This entails constantly improving logistical procedures to cut down on lead times and operating expenses while maintaining resource availability at the most critical times and locations. Maintaining military success in a world that is becoming more complicated requires the ability to react quickly to shifting operational needs (Logistics, 2024; Chau, 2025).

Case Studies

1. Shifting to Just-in-Case Supply Chains

One important step in improving military logistics resilience has been the shift from conventional just-in-time (JIT) supply chain models to just-in-case (JIC) strategies. Military logistics has started to emphasize resilience by keeping strategic inventories to guarantee continuity during crises as disruptions, both anticipated and unanticipated, have put the effectiveness of JIT systems to the test more and more (Cade, 1971; Dowd, et al.,2023). This change not only improves operational preparedness, particularly in the defense industry, but it also brings with it a number of difficulties that must be overcome in order to make logistical operations more flexible and effective (Brimage-Gray, 2024).

2. Prioritizing Fuel Support and Operational Energy

Fuel support requirements and operational energy needs have been prioritized and estimated using analytical methods like modeling and simulation. The crucial role that operational energy plays in combat effectiveness was emphasized in a 2015 RAND paper that created a methodology that could be mode-led for NATO. The significance of more strategic resource management was underlined there (Services, 2021; Fox, 2024; Insight, 2024). NATO is urged to use the NATO Innovation Fund and its Defense Innovation Accelerator for the Northern Atlantic to find and apply cutting-edge technical solutions, such as artificial intelligence, to maximize fuel efficiency in support of military operations (Quora, 2024).

3. Contested Logistics Challenges

Army leaders have identified contested logistics as a significant obstacle for upcoming wars. In order to solve logistics issues, especially in complicated operating contexts, industry-military collaborations have become essential. For instance, General Dynamics Land Systems highlights the need of forming alliances with top organizations in order to use a variety of skills that satisfy unique operations needs. In order to overcome contentious logistics issues, this strategy promotes teamwork rather than isolation, which could endanger operational success(Gaffney, 2008; Kobren, 2010; Heckmann, 2023).

4. Technological Adaptation and Transformation

Because of the speed at which technology is developing, military logistics are always changing. In order to adjust logistics systems across periods ranging from 18 months to 15 years, the Army Futures Command is aggressively addressing these changes. This adaptive strategy emphasizes the necessity for quick and precise data to improve decision-making processes in order to give soldiers a competitive edge in a convoluted and contested logistics environment (Fenema et al., 2021; Insights, 2024). The key question is still how long the military ecosystem can survive in such circumstances, where efficiency is crucial and chaos in logistics operations is a real possibility (Marine, 2023; Sander, 2024b).

Challenges and Limitations

The adoption of effective risk-responsive solutions is complicated by the enormous obstacles faced by military logistics. Following the 7R formula, which stresses delivering the right product at the right time and in the right quantity, is one of the biggest challenges (America, 2021). Logistics challenges include varying demand, long distances, and poor infrastructure frequently impede this need, which calls for a high level of flexibility in logistics procedures(America, 2021; Logistics, 2024).

1. Limitations on Resources

The present under-resourcing of capabilities is a significant constraint in military logistics. The demands of future military operations are frequently not met by current logistical frameworks, particularly in the event of a crisis that calls for quick adaptation and scaling(Services, 2021; Logistics, 2024). The military must transition from conventional approaches that only concentrate on effective supply delivery to more sustainable techniques that take into account fluctuating demands and potential disruptions as its reliance on overburdened logistics networks grows (Lacroix, 2022).

2. Contesting Logistics Environments

Traditional supply and delivery techniques are losing their effectiveness as military operations change, especially in disputed logistics contexts. Commanders of Special Operations Forces (SOFs) are constantly reassessing their logistical strategies to adapt to the demands of evolving war zones. In order to reduce the logistics footprint and enable more strategic maintenance planning, this involves using predictive analytics to optimize the deployment of vehicles and equipment (Kobren, 2010; Sani et al., 2022; Surridge, 2024). There is a trend toward providing only what is necessary at the time of demand, rather than depending on past data to account for uncertainties (Roncolato, 2024; Sani, et al., 2022).

3. Globalization and Geopolitical Risks

Military logistics become much more complicated as a result of globalization. The idea that "the homeland is no longer a sanctuary" captures the fact that contentious logistics can occur in a variety of contexts and necessitate real-time operational modifications (Insight, 2024; Shelia, 2024). Global catastrophes can cause disruptions that affect supply chains and logistical networks across continents, as demonstrated by the NotPetya cyberattack and other ripple effects (Insight, 2024; Rajesh, 2024). Military logistics must therefore deal with erratic geopolitical environments that can seriously impair the timely delivery of supplies.

4. Partnering for Success

The changing logistics environment emphasizes how crucial it is for different parties to work together. Improving logistics capabilities and guaranteeing the supply of key commodities in response to new problems need involving partners from the industrial base, other government agencies, and the Department of Defense (DoD) (Mohammed, et al., 2023; Sarah, 2025a). To improve the agility of logistics platforms, a successful collaboration will require knowledge of data management, strong security protocols, and a culture of constant innovation (Mohammed, et al., 2023; Sarah, 2025a).

Future Directions

Military logistics must change to maintain the robustness and effectiveness of supply chains in the face of changing global challenges. To improve military logistics networks, a strategic framework that prioritizes cooperation and innovation will be essential. The intricacies of Joint Integrated Capability (JIC) supply chains must be addressed with a clear vision and proactive guidance from important military and governmental players. Using scenario-based planning and sound military judgment, this entails anticipating future needs and emergencies. (Sander, 2024b; Surridge, 2024).

1. Collaborative Approaches

Successful logistical operations require cooperation between the Department of Defence, other governmental organizations, and the industrial base both locally and abroad. Military logistics can be better equipped to fulfil surge requirements and efficiently respond to emergencies by sharing commercial risks with the Ministry of Defence (MoD) and cultivating long-term confidence in demand (Reddit, 2021; Insights, 2024). Military supply chains can be made faster and more efficient by integrating robotic logistics support systems and automated warehouses (Insights, 2024).

2. Technology Integration

Incorporating cutting-edge technologies, especially data analytics and artificial intelligence (AI), will be crucial to improving military logistical decision-making. Commanders can anticipate adversary movements, logistical bottlenecks, and possible supply chain disruptions with the use of AI, which can give real-time information and spot trends that human analysts would not notice (Sani, et al.,2022; Fox, 2024). Military leaders will be better equipped to make judgments and keep a competitive edge on the battlefield thanks to such technical improvements (Rajesh, 2024).

3. Resilience and Adaptability

Investing in infrastructure upgrades, such as more storage space and improved cybersecurity, is necessary to make military logistics networks more resilient. These improvements will reduce the risks associated with contested environments by guaranteeing that logistical operations can tolerate disruptions, whether they are caused by hostile acts or natural disasters (Surridge, 2024; Torres, 2025).

“We are in a race of logistics,” as NATO Secretary General Jens Stoltenberg put it, highlighting the significance of robust and interoperable logistics in the current security environment. To sustain operations across all domains air, sea, land, space, and cyber military logistics must continue to evolve with an emphasis on these crucial areas. This will ensure that forces can effectively respond to new threats and maintain operational readiness in an uncertain world (Sander, 2024a; Torres, 2025)

Conclusion

In the complicated security context of today, improving risk-responsive military logistics networks is essential. Military supply chains need to move past conventional efficiency-focused models and toward more robust frameworks that can tolerate both deliberate disruptions and systemic shocks, as this investigation has shown. A basis for sustainable logistics operations in disputed environments is provided by the strategic transition from just-in-time to just-in-case techniques, as well as by technological integration and cooperative partnerships. Operational resilience can be achieved practically through implementation strategies that emphasize cybersecurity, predictive analytics, and backup supply lines. "We are in a race of logistics," as NATO Secretary General Jens Stoltenberg eloquently put it, emphasizing the strategic significance of logistics mastery in contemporary combat. To guarantee that logistics networks continue to be flexible, responsive, and capable to support military operations across all domains in spite of local market uncertainty and global irregularities, military organizations must make ongoing investments in infrastructure, technology, and cross-sector collaboration.

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ADAPTIVE PROCUREMENT RISK MANAGEMENT STRATEGIES FOR SUPPLY CHAIN RESILIENCE IN VOLATILE GLOBAL MARKETS

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Abstract

In a progressively unstable global market, procurement operations face significant pressure to manage disruptions arising from geopolitical tensions, pandemics, natural disasters, and economic volatility. This study examines adaptive procurement risk management solutions that enhance supply chain resilience in uncertain circumstances. This research applies a qualitative research approach, featuring semi-structured interviews with 25 procurement and supply chain professionals across diverse sectors, such as production, healthcare, retail sector, and technology, in conjunction with document analysis and case studies executed during a six-month duration in 2024. The findings reveal four critical themes: proactive risk recognition and evaluation, strategic management of supplier relationships, integration of digital technologies, and execution of resilience-focused procurement processes. Organisations are increasingly using technologies such as analytics for prediction, blockchain technology, and artificial intelligence to enhance visibility, traceability, and decision-making in uncertain environments. Supplier diversification, collaborative alliances, adaptable sourcing, and scenario analysis are identified as fundamental measures for risk mitigation. This research emphasises the necessity for a comprehensive, flexible, and proactive strategy in procurement risk management that integrates digital innovation with strategic planning and stakeholder collaboration. This research summarises lessons from practice and literature to provide actionable recommendations for supply chain professionals and policymakers aiming to develop resilient and adaptable procurement systems that can endure global crises and maintain operational continuity.

Key Words: Adaptive procurement, supply chain resilience, risk management, global disruptions, digital technologies, supplier diversification

Introduction

In the contemporary global environment, supply chains have grown progressively intricate and susceptible to various disruptions. Geopolitical tensions, natural disasters, pandemics, economic instability, and cyber threats have revealed the vulnerability of conventional supply chain frameworks. The COVID-19 pandemic notably acted as a catalyst, affecting global production and logistics networks while exposing substantial deficiencies in procurement and risk management methods (Christopher & Peck, 2004;

Ivanov, 2020). These difficulties have highlighted the necessity for organisations to rethink their procurement strategies to achieve enhanced resilience and adaptation in a VUCA (volatility, uncertainty, complexity, and ambiguity) environment (Bhatnagar & Sohal, 2005).

Traditionally, procurement has been perceived as a cost-centric, transactional activity, frequently motivated by objectives such as expenditure reduction via just-in-time (JIT) systems, lean inventory practices, and global sourcing (Harrison & van Hoek, 2005). Although efficient in steady situations, these efficiency-oriented strategies frequently falter after abrupt and extensive disruptions (Ponomarov & Holcomb, 2009). The emphasis has transitioned to developing supply networks that are both efficient and resilient—able to anticipate, absorb, and recover from disturbances (Sheffi, 2007; Norrman & Jansson, 2004).

Procurement is crucial in obtaining supply chain resilience. The strategic significance has markedly increased as organisations acknowledge that supplier selections, sourcing strategies, and risk management initiatives directly influence the continuity of operations (Choi & Linton, 2020; Monczka et al., 2015). Adaptive procurement techniques encompass proactive risk assessment, strategic management of supplier relationships, diversification of supply sources, and the incorporation of contingency planning into procurement procedures (Kaufmann & Carter, 2004; Dyer & Hatch, 2006).

The growing adoption of digital technologies further supports this shift. Innovations like blockchain technology, artificial intelligence (AI), machine learning, and predictive analytics are transforming procurement practices by improving supply chain visibility, data accuracy, and response times (Huang & Wei, 2021; Klaus & Krieger, 2020; Sarkis et al., 2019). Predictive analytics, for instance, can forecast potential disruptions using historical and real-time data, enabling procurement teams to take preemptive actions. Blockchain enhances traceability and trust, while AI improves supplier selection and demand forecasting (Aven, 2015; Hajialiasghari et al., 2019).

Supplier diversity has become an essential strategy. Dependence on a singular or restricted number of providers heightens susceptibility during crises. By diversifying their sources across several locations and supplier categories, organisations can more effectively offset risks related to geographical interruptions, raw material shortages, or unstable political circumstances (Choi & Linton, 2002; Parker et al., 2015; Hines, 2004). Alongside technical and structural modifications, resilience-focused procurement strategies, including flexible sourcing, planning for possible scenarios, and sustainable procurement, are becoming significant. Flexible sourcing allows organisations to rapidly change suppliers or products in reaction to market fluctuations, whereas scenario planning prepares them to anticipate and address diverse disruption scenarios (Sullivan & Steven, 2020; Harrison & Hoek, 2014). Moreover, sustainable and ethical sourcing strategies enhance long-term stability and mitigate risks related to social, environmental, and reputational factors (Carter & Rogers, 2008; Harrison et al., 2018).

In light of these developments, it is clear that procurement operations must adapt to encompass a wider array of risks while facilitating organisational agility and sustainability. This study investigates the ways in which adaptive procurement risk management solutions can enhance supply chain resilience in a progressively volatile global environment. This research seeks to elucidate the role of strategic procurement in developing resilient and future-proof supply chains by synthesising ideas from academic literature and industry practices. The results aim to guide procurement professionals, policymakers, and organisational leaders in addressing the challenges of the digital age and in transforming procurement into a vital facilitator of resilience and competitiveness.

Literature Review

The global marketplace is experiencing significant changes, marked by heightened volatility, uncertainty, complexity, and ambiguity (VUCA). The dynamic changes driven by geopolitical conflicts, pandemics, climate change, natural disasters, and economic instabilities have revealed the vulnerability of conventional, efficiency-focused supply chain models. The emphasis has transitioned to supply chain resilience, especially within procurement functions, which are essential for maintaining continuity and performance during disruptions. This literature review examines the significance of resilient supply chains, the transformation of procurement into a risk-mitigating strategic function, and the incorporation of technologies and ethical principles that facilitate adaptive procurement in a dynamic environment.

Supply chain resilience is broadly characterised as an organization's capacity to anticipate, react to, and recuperate from unforeseen interruptions while ensuring operational continuity (Ponomarov & Holcomb, 2009). Historically, supply chains were structured according to lean principles and just-in- time (JIT) delivery to reduce costs and enhance efficiency. Nevertheless, these procedures frequently allow less flexibility during disturbances (Christopher & Peck, 2004). The COVID-19 pandemic acted as a global alert, revealing the systemic deficiencies of these paradigms and the urgent necessity for a paradigm shift (Ivanov, 2020). Integrating resilience into supply chains necessitates a balanced strategy maintaining operational efficiency while incorporating attributes such as agility, flexibility, and redundancy (Sheffi, 2007; Jüttner et al., 2003). Procurement plays a crucial role in regulating sourcing strategy, supplier alliances, and vulnerability to external disruptions. Consequently, procurement risk management is evolving from an operational issue to a fundamental strategic function in efforts to enhance resilience (Carter & Rogers, 2008).

Adaptive procurement denotes the capacity of procurement systems to flexibly react to fluctuations in risk settings. In contrast to conventional procurement, which primarily emphasises cost reduction and supplier performance in standard circumstances, adaptive procurement focusses on flexibility, resilience, and proactive risk assessment (Monczka et al., 2015). Adaptive risk management entails the ongoing identification, analysis, and mitigation of procurement-related risks, including supplier insolvency, material shortages, and geopolitical trade obstacles (Moktadir et al., 2020). The capacity to swiftly alter sourcing strategies, execute contingency plans, and reorganise supply networks is essential in unstable markets. This proactive strategy enables organisations to not only endure crises but also potentially acquire a competitive edge by reacting more rapidly than rivals (Kaufmann & Carter, 2004).

Proficient risk identification is essential for procurement resilience. Organisations must methodically chart their supply chains and pinpoint weaknesses at each node, encompassing tier-1 and sub-tier suppliers, logistical partners, and geopolitical regions (Jüttner et al., 2003). Procurement risk assessment encompasses multiple categories, including financial risk (e.g., supplier insolvency), operational risk (e.g., quality deficiencies), geopolitical risk (e.g., trade embargoes), and environmental risk (e.g., natural calamities). Various methods and frameworks facilitate risk prioritisation, such as risk matrices and failure mode and effects analysis (FMEA), which assist organisations in assessing the probability and consequences of particular procurement risks (Kaufmann & Carter, 2004). Strategic sourcing methods, including supplier diversity, dual sourcing, and localisation, are frequently utilised to alleviate recognised risks (Caniëls & Gelderman, 2007; Zsidisin & Wagner, 2010).

Effective supplier relationship management (SRM) is essential for risk minimisation. Robust, trust- centric relationships with essential suppliers can enhance visibility, communication, and collaborative problem-solving, especially in times of crisis (Dyer & Hatch, 2006). Collaborative Supplier Relationship Management facilitates partners in exchanging early alerts regarding potential disruptions and collaboratively developing mitigation strategies (Choi & Linton, 2002). High- performing procurement teams cultivate strategic partnerships by consistent engagement, performance indicators, and collaborative innovation initiatives (Krause et al., 2007). Flexible and interconnected supplier networks offer organisations several sourcing options, essential for swift responses during interruptions (Hines, 2004). Ultimately, Supplier Relationship Management (SRM) mitigates risks while fostering long-term value co-creation and enhancing supply chain agility (Harland et al., 2003).

Digital transformation is revolutionising procurement procedures and markedly improving resilience. Technologies such predictive analytics, blockchain technologies, artificial intelligence (AI), and the Internet of Things (IoT) empower procurement teams to identify, assess, and address risks in real- time (Klaus & Krieger, 2020). Predictive analytics employs historical and real-time data to anticipate demand fluctuations, supplier disruptions, or geopolitical alterations, facilitating more proactive procurement strategies (Aven, 2015; Huang & Wei, 2021). Blockchain enhances supply chain transparency and traceability by establishing secure, immutable transaction records, hence mitigating risks associated with fraud and counterfeiting (O’Neill & Strassner, 2020; Sarkis et al., 2019). The Internet of Things (IoT) improves operational visibility by investigating shipments, real-time monitoring of environmental variables and equipment performance (Pereira et al., 2020). These technologies jointly facilitate enhanced decision-making, increased supplier accountability, and expedited disruption response.

Reliance on a one supplier or geographic area markedly elevates procurement risk. Consequently, supplier diversification is a broadly supported resilience strategy. It distributes risk across various sources, offering redundancy and adaptability (Choi & Linton, 2002). Throughout the COVID-19 pandemic, organisations possessing varied supplier bases were more adept at maintaining operations despite worldwide disruptions. Adaptive sourcing solutions enable procurement teams to swiftly change suppliers or replace materials according to availability and market fluctuations (Harrison & Hoek, 2014). Dual sourcing guarantees continuity by procuring the same product from multiple suppliers (Lau & Zhao, 2018). Geographic diversification safeguards corporations against region- specific risks, including natural disasters and political instability.

Methodology

This study utilised a qualitative, multi-method approach to obtain in-depth perspectives from industry professionals and academic specialists. This comprehensive research incorporated semi- structured interviews, review documents , and case studies, ensuring a complete understanding of the key strategies and processes employed to mitigate procurement risks and develop resilient supply chains.

Data collection occurred across six months, from June to December 2024, utilising purposive selection to select individuals with substantial skill and experience in procurement and supply chain management. The sample comprised 25 people from various sectors, comprising manufacturing, healthcare, retail, and technology, so providing a variety of perspectives. Participants were chosen according to their positions requiring a minimum of five years of pertinent experience. The interview protocol was designed with open-ended questions to investigate participants' experiences with procurement risk management, strategies for risk mitigation, and methods for constructing resilient supply chains amid global disruptions, including geopolitical tensions, natural disasters, and economic instability.

Semi-structured interviews were performed using video conference, with durations ranging from 40 to 75 minutes. All interviews were conducted with participants' consent, transcribed verbatim, and analysed for emerging themes. The adaptability of semi-structured interviews enabled participants to expand on their experiences and offer nuanced perspectives regarding the tactics utilised in procurement risk management. This strategy yielded valuable, primary data crucial for comprehending the intricacies of procurement decisions in unstable contexts.

Alongside the interviews, document analysis was performed to augment the main material. The analysed resources comprised industry reports, organisational procurement policies, academic publications, and white papers pertinent to procurement risk management and supply chain resilience. The emphasis was on materials released in the past five years to guarantee that the research reflected the latest trends and practices.

This analysis was employed to corroborate findings from the interviews and to furnish supplementary context for the tactics mentioned by participants.The materials were chosen for their their significance, validity, and recent publication dates to guarantee that the research aligned with contemporary industry norms and best practices.

Case studies constituted a vital element of the research approach, providing practical insights into the application of adaptive procurement risk management strategies by individual organisations to bolster supply chain resilience. Three case studies were created utilising publically accessible information and further insights obtained via interviewees. The case studies examined organisations across many sectors, including a multinational electronics company, a healthcare supply chain provider, and a major retail corporation. The case studies demonstrated practical implementations of procurement risk management methods, including the integration of digital technologies, supplier diversification, and scenario planning, and how these tactics enabled organisations to effectively manage global disruptions.

Thematic analysis, a prevalent method for examining qualitative data, was employed for data analysis. Thematic analysis facilitated the recognition of repeating patterns, trends, and principal themes derived from the interview transcripts, document analysis, and case study data. The coding approach was iterative, encompassing several review cycles to enhance and unify the concepts. Preliminary codes were developed in accordance with the study questions and insights derived from the literature review, while supplementary codes surfaced throughout the data analysis. The codes were categorised into overarching themes that encapsulated the core of participants' experiences and viewpoints regarding procurement risk management.

Triangulation was utilised to guarantee the validity and reliability of the results. Triangulation entailed the comparison of data from many sources interviews, papers, and case studies. Additionally, member verification was utilised to confirm the accuracy of the interview scripts and their interpretations of them. Participants were provided with summaries of the findings and permitted to contribute feedback, which was incorporated into the final analysis to ensure the research accurately reflected their perspectives and experiences.

Ethical considerations were thoroughly addressed throughout the research process. Informed consent was obtained from all participants, who were assured of anonymity and confidentiality of their responses. Data was meticulously safeguarded to protect participants' privacy, and all ethical regulations regarding rights of participants and data protection were rigorously adhered to. The research design and methodology were developed to ensure that the results would provide valuable information for policymakers and practitioners in procurement and supply chain management, thereby facilitating the creation of adaptive procurement strategies to enhance supply chain resilience in volatile global markets.

This study utilised a meticulous and thorough methodology to investigate adaptive procurement risk management solutions. The integration of semi-structured interviews, document analysis, and case studies, underpinned by thematic analysis and triangulation, established a comprehensive framework for comprehending the strategies and practices utilised by organisations to enhance supply chain resilience and alleviate procurement risks in a progressively unstable global context.

Results and Findings

This study analysed adaptive procurement risk management solutions that improve supply chain resilience in the context of volatile global conditions. Leveraging qualitative methods interviews, document analyses, and case studies four principal themes emerged: risk identification and assessment, supplier relationship management, digitalisation, and strategic resilience strategies. These findings elucidate the dynamic and multifaceted characteristics of procurement risk management across various industries.

1. **Identification and Evaluation of Risks**. Participants underscored the proactive recognition of hazards throughout the supply chain. Three primary categories of risks were identified: operational risks (e.g., financial turmoil, delivery delays), market risks (e.g., prices volatility, geopolitical concerns), and enviromental risk (e.g., natural disasters, political instability). Supplier-related risks were the most commonly mentioned, highlighting the necessity for rigorous evaluation methods to predict and alleviate disruptions.

Risk Category	Frequency	Specific Risks
Operational Risks	High	Financial turmoil, quality control issues, delivery delays
Market Risks	Medium	Price fluctuations, scarcity, geopolitical uncertainty
Environmental Risks	High	Pandemics, natural calamities, regulatory modifications

Table.1 : Principal risks recognised in procurement risk management
Source: Author

2. **Supplier Relationship Management**. Robust supplier relationships were deemed essential for risk management and guaranteeing continuity. Essential practices encompassed routine audits, enduring relationships, cooperative risk management, and supplier diversification. These tactics foster transparency, trust, and collective accountability for risk minimization.

Practice	Frequency	Examples
Routine Audits	High	Financial, quality, and compliance assessments
Long-Term Partnerships	High	Strategic alliances, multi-year contracts
Cooperative Risk Management	Medium	Joint risk planning
Supplier Diversification	Medium	Multi-supplier sourcing, geographic spread

Table 2 : Key practices in supplier relationship management
Source: Author

3. Digitalization in Procurement Risk Management. Digital solutions are being utilised to improve risk visibility and decision-making. Predictive analytics was the most employed, succeeded by blockchain, advanced analytics, and nascent AI applications. These technologies facilitate early warning systems, enhance traceability, and provide real-time decision support.

Technology	Frequency	Applications
Predictive Analytics	High	Forecasting disruptions
Blockchain	Medium	Traceability, compliance
Advanced Analytics	Medium	Scenario analysis
AI	Low	Automated risk detection

Table 3 : Key practices in supplier relationship management
Source: Author

4. Strategic Resilience Practices. Organisations implemented resilience techniques which provide continuity and adaptability under pressure, facilitating expedited recovery and more steady operations.

Practice	Frequency	Examples
Inventory Buffering	High	Safety stock, stockpiling
Redundancy	Medium	Backup suppliers, alternative logistics
Flexible Sourcing	Medium	Numerous vendors, flexible contracts
Scenario Planning	Medium	Established disruption response strategies

Table 4 : Practices for Strategic Resilience
Source: Author

Discussion

This study enhances the existing literature regarding supply chain resilience through the provision of a comprehensive analysis of how organisations modify procurement risk management techniques in reaction to global shocks. The results from interviews, document analysis, and case studies align with current research, confirming that developing resilient supply chains necessitates a proactive, strategic, and technology-integrated procurement strategy.

Risk Identification and Assessment has emerged as a critical subject, consistent with prior research that underscores the necessity for organisations to transcend superficial risk evaluations (Ponomarov & Holcomb, 2009). The research categorised operational, market, and environmental risks as primary types, reflecting the frameworks proposed by Jüttner et al. (2003) and Kaufmann & Carter (2004). The emphasis on supplier-related risks highlights the critical need to assess financial stability, quality control, and reliability in sourcing partners.

Supplier Relationship Management constituted another essential element. Robust relationships founded on transparency, mutual trust, and enduring collaboration not only augment risk communication but also bolster collective problem-solving capacities during crises (Dyer & Hatch, 2006; Krause et al., 2007). The regular implementation of periodic audits and collaborative planning indicates a transition from transactional to strategic supplier interaction, as evidenced by Harland et al. (2003). Furthermore, supplier diversification encompassing both geographical and categorical dimensions has surfaced as a calculated risk-mitigation technique, aligning with the findings of Choi & Linton (2002) and Parker et al. (2015).

Digitalisation is converting procurement from a reactive to a predictive function. The prevalent utilisation of predictive analytics among participants reinforces the emerging agreement on data- driven risk management (Huang & Wei, 2021; Klaus & Krieger, 2020). The adoption of blockchain, however moderate, illustrates its potential to enhance transparency, particularly in monitoring compliance and verifying product authenticity (Sarkis et al., 2019). The nascent development of AI signifies an increasing interest in automation and real-time decision assistance, aligning with the research of Hajialiasghari et al. (2019) and Aven (2015).

Strategic Resilience Inventory buffering, redundancy, and scenario planning signify a transition from lean-exclusive systems to hybrid models that prioritise agility and preparation (Sheffi, 2007; Harrison & Hoek, 2014). These techniques improve adaptation and allow organisations to sustain continuity during unexpected disruptions. Scenario planning, specifically, was determined to provide organisations with foresight, corroborating Sullivan & Steven's (2020) claim that scenario-based thinking enhances disaster preparedness.

The results also indicate a cohesive mentality within high-performing procurement functions. Instead of viewing risk management as a separate function, these organisations integrate it into comprehensive procurement strategies and sustainability goals. This comprehensive approach aligns with Carter & Rogers' (2008) assertion that ethical and sustainable procurement methods substantially enhance long-term resilience by alleviating reputational, environmental, and social risks.

The triangulation of data from interviews, documents, and case studies enhances the analysis and verifies that effective procurement resilience strategies are not confined to a specific industry but are broadly applicable across various sectors, including retail, manufacturing, healthcare, and technology.

Conclusion

This research investigated how organisations are addressing increasing global volatility by implementing adaptive procurement risk management strategies to enhance supply chain resilience. A qualitative, multi-method study involving 25 professionals from various industries identified four primary strategies utilised by organisations: (1) proactive identification and assessment of risks, (2) strategic supplier relationship management, (3) digitalisation of the procurement processes, and (4) implementation of resilience-focused practices.

The analysis illustrates that procurement has evolved from a marginal activity focused solely on cost reduction to a strategic cornerstone essential for organisational resilience. Risk assessment frameworks, together with digital advances such as predictive analytics and blockchain, enable organisations to foresee and address hazards more efficiently. Robust supplier relationships founded on collaboration and trust enhance the ability to adjust amid disruptions.

Additionally, strategies such supplier variety, flexible sourcing, inventory buffering, and scenario planning improve supply chain agility and continuity. These data validate that a transition from reactive to proactive procurement management is occurring, supported by technology and strategic alignment.

In summary, adaptive procurement risk management is essential and serves as a strategic advantage in navigating the contemporary VUCA environment. Organisations that adopt these adaptable methods are more effectively equipped to maintain operational continuity, safeguard stakeholder value, and sustain competitiveness in the face of persistent global volatility. This study offers practical insights for procurement professionals, supply chain managers, and policymakers aiming to fortify their supply networks with resilient procurement practices.

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ADAPTIVE MILITARY LOGISTICS IN HYBRID WARFARE: LEVERAGING LESSONS FROM GLOBAL CONFLICTS FOR SRI LANKA'S RESILIENT DEFENCE SUSTAINMENT

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Abstract

This paper examines how Sri Lanka can transform its vulnerable strategic position in the Indian Ocean into strength through adaptive defense logistics. Drawing lessons from the Ukraine War, Gaza Conflict, and Indo-Pacific tensions, it proposes solutions to enhance resilience against hybrid warfare threats. Domestic industrial development-repurposing textile factories for military gear and promoting agro-tech startups-can reduce import dependency following the 2022 economic crisis. Digital innovations including blockchain for inventory tracking and AI-based maintenance would improve efficiency and cybersecurity. The development of multi-domain logistics hubs, particularly Trincomalee Port, could enhance rapid-response capabilities. Civilian-military cooperation models from Ukraine and Gaza demonstrate how grassroots ingenuity converts to tactical advantages. Sri Lanka requires policies balancing non-alignment with strategic partnerships like India's "Make in India" initiative. An integrated approach incorporating decentralized supply chains, dual-use technologies, and interoperable alliances can simultaneously strengthen defense capabilities and economic resilience in an increasingly contested Indian Ocean region.

Key Words: Adaptive logistics, hybrid warfare, Sri Lanka, military civil collaboration, indo-pacific security

Introduction

1. Hybrid Warfare and Its Logistical Challenges

Hybrid warfare combines conventional military tactics with irregular ones using cyber-attacks, disinformation, and proxy forces. Such multi-domain ambiguity raises complex logistic problems for the conduct of this warfare (Hoffman, 2007). Unlike traditional battles, hybrid conflicts are probably able to exploit decentralized environments, exploiting civil infrastructures and dual-use technologies, thereby complicating supply-chain management and consequentially, threat attribution.

One of the crucial logistical problems is that the adversaries intermingle with civilian populations, mainly using tactics like those perfected by Hezbollah during the 2006 Lebanon War: the concealment of weapons within cities and tunnel networks to resist directly against the superior military. In this way, the need for agile logistics in counteraction of clandestine supply lines became evident (Deshpande, 2018).

Hybrid actors exploit commercial technology, thereby enhancing operational flexibility. For example, Hezbollah's use of Iranian UAVs to blind Israeli eyes, demonstrated how these cheap platforms can neutralize traditional advantages (Deshpande, 2018). This calls for logistics that can counter cyber-physical disruptions posed by these threats, including attacks on energy grids or transport hubs.

The mingling of civil and military entities extends the logistic challenges. In Ukraine, Russia's hybrid warfare, met by cyber-attacks and proxy warfare, caused disruptions to supply lines that depended heavily on civilian networks (Alkema and Melenchuk, 2022). Such a scenario imposes requirements on technology, non-redundancy, and rapid resource reallocation, as well as interfacing with non-military actors.

Grey-zone operations, such as China's incremental territorial expansion in the South China Sea, will make preemptive logistic investments in surveillance and mobility for deterrence of the encroachment irresistible (Yadav, 2019).

2. Geopolitical Position of Sri Lanka (Indian Ocean Strategic Corridor) and Vulnerabilities

The strategic position of Sri Lanka in the Indian Ocean, a link for global maritime trade and energy flows, is an aspect that makes it a very important point for geopolitical competition among major powers like India, China and the United States (Premaratne, 2020). Such centrality increases the vulnerabilities in Sri Lanka.

a. **Economic Crisis**. It made worse by the overdependence on foreign loans to develop infrastructures, especially with regard to the plan of BRI China. This made the year 2022 so economically depressed because it was brought about by the debt-induced collapse (Premaratne, 2020). The crisis itself proved that economic sovereignty could be undermined by geopolitical entanglement.

b. **Dependence on Imports**. More than 80 percent of the necessary commodities (including pharmaceuticals and fuel) imported to Sri Lanka (Premaratne, 2020). Trade route disturbance in the Indian Ocean is highly vulnerable to regional tensions or piracy (Irfan, 2023). These shall aggravate supply chain risks, subjecting the island to the external shocks. While taking care of structural import reliance, it is still utmost importance balancing geopolitical pressures in terms of resilience.

Case Studies from Global Conflicts

1. Ukraine War

a. Use of Decentralized Logistics Networks. The war in Ukraine shone a spotlight on decentralized logistics as a life support to supply chains, damaged by infrastructure destruction and the collocation of frontline vulnerability. Ukrainian forces and businesses reacted to such dislocation by establishing agile networks utilizing cloud-based systems for real-time tracking and blockchain for data management (Bondar-Pidhurska et al., 2023). Others, including civilian volunteers and grassroots networks, collaborated with military units to transport essentials past blockades. Drones and 3D printing were enlisted to expedite last-mile deliveries of medical supplies and spare parts. The decentralized approach in this case was one of diminishing dependence on centralized hubs that can be vulnerable to targeted strikes while adopting EU sponsored programs such as the TEN-T in efforts to restore connectivity (Bondar-Pidhurska et al., 2023).

b. NATO Supply Chains. Logistical support of NATO for Ukraine was stressing the multinational dimension, using hubs in Poland, Romania, and Slovakia to streamline arms transfers and humanitarian aid (Trif & Dumitraşcu, 2025). The real-time blockchain supply chain transparency enhanced private-sector partnerships, which sped up the production and delivery of equipment under the sponsorships of NATO. Not having made decisions in time, the result of all this was a $50 billion aid package that would make Ukraine more resilient to infrastructure disruption (Trif & Dumitrascu, 2025). Training programs improved local logistics expertise, last-mile delivery aided by drone integration, all of which showcase the value of interoperable, tech-driven alliances, and these are lessons that Sri Lanka could learn from to enhance its agility in terms of supply chain management regarding hybrid threats.

c. Civilian-Military Partnerships. The Ukraine conflict proved that civil-military relationships are key to sustain logistics under the conditions of hybrid warfare. Private firms like Rheinmetall set up hubs for repair in Romania to fix Western supplied equipment (Trif & Dumitrascu, 2025), while Leopard 2 tanks were serviced at Poland's Bumar-Labedy plant. Infrastructure used by civilians, such as Danube ports like Constanta, emerged as key to diverting Ukrainian exports after the blockades of the Black Sea, with 85 percent of border crossings being handled by private rail and trucking firms (GMK Center, 2024). Humanitarian and military supplies were able to reach their destinations without any difficulties by road, thanks to the EU-Ukraine agreements that exempted the transport permits (Trif & Dumitrascu, 2025). These sorts of collaboration verify that the integration of civilian networks gives supply chain resiliency amid disruption.

d. Role of Drones and AI in Real-Time Resource Allocation. AI drones have revolutionized real time resource allocation during the Ukraine war by dynamic adjustments in logistics. Supply routes are autonomously optimized by AI, which prioritize high value targets and also reduce delays caused by human error. Thus, their utility on the frontline has become more flexible (Bondar, 2024). Predictive AI then predicts reductions and simulates various scenarios regarding the logistics. Autonomous navigation systems boost the effectiveness of missions by 70-80% even amid disruption from electronic warfare (Goncharuk, 2024). Delta has become a responsible collaborative platform integrating real time data from drones and sensors, simplifying decision-making toward rapid responses (Bondar, 2024). This proves the importance of innovations with AI for sustaining the defence of Ukraine under resource constraints.

2. Gaza Conflict

a. Challenges of Sustainment in Blockaded Environments. The Gaza Conflict shows severe sustainment challenges in blockaded environments where conventional logistics are ripped apart by restrictions on goods and movement. The current blockade imposed by Israel since 2007 has severely limited imports of fuel, medical supplies, and construction materials, forcing reliance on periodic humanitarian aid convoys and UN-coordinated deliveries (OCHA, 2023). The unpredictable supply chains further aggravate the already existing shortages of essentials like electricity and clean water. Border closures and aerial bombardments on infrastructure -notably roads and warehouses- also further weaken military and civilian sustainment efforts (Finkelstein, 2021). Thus, systemic demands have not been satisfactorily met, thereby underlining the importance of resilient, decentralized logistics frameworks in hybrid warfare contexts to mitigate the impact of the bottlenecks.

b. Reliance on Underground Supply Networks. Many underground tunnels in Gaza have only fate attached to mark lines which have been used to sneak on a blockade - all described within the context of clandestine movement of food, flame, and weaponry. Some extend into Egypt although they avoid detection and airstrikes with Israeli countermeasures degrading their efficiency (Crisis Group, 2022). Hamas and other regional militias use tunnels for transactional operations; civilians, on the other hand, have used tunnels to access commodities during extended sieges. Ventilation systems; structural reinforcement; everything unexpected underpin operational complexity of the tunnels; such complexities act adaptive innovation under duress (Roy, 2020). However, reliance on such networks is risky because they may just as likely collapse in bombardment or fall into the hands of armed groups. And thus, the delicate balance between survival and vulnerability in blockaded conflict zones.

3. Indo-Pacific Tensions

a. Securing maritime logistics in contested waters. Maritime logistic security in the contested waters of the Indo-Pacific, same as, the South China Sea, must also contend with weaknesses to be exploited by China anti-access or area-denial capabilities and sheer geographical distances. To mitigate the risks, the U.S. military has emphasized predictive logistics and technical interoperability. For instance, the AI analytics engine Advana allows real-time visibility into materiel and personnel to inform decisions in the timing of disruptions induced by adversarial gray-zone tactics or direct attacks on supply routes (Georgetown Security Studies Review, 2024).

Distributed logistic architecture is underlined by the United States, supported by the Marine Corps's Force Design 2030, which envisages forward-deployed, smaller units supported by agile prepositioning networks to reduce dependency on centralized hubs, thus enhancing resilience. Other interoperability initiatives, like with Japan and Australia, are also helpful. In this case, joint exercises like RIMPAC integrate joint data standards and zero-trust cybersecurity architectures, thereby ensuring logistics-related information remains sensitive while permitting multilateral coordination (FPRI, 2025). In addition, a firm push to modernize sealift capabilities and diversify supply routes -commercial partnerships or any arrangements for regional resupply- would be vital to overcoming the bottleneck posed by contested chokepoints like the Panama and Suez Canals (Mercogliano, 2024).

Strategic Adaptations for Sri Lanka

1. Localized Supply Chains

According to the World Bank, 85 percent of military equipment in Sri Lanka is imported, and this leads to vulnerabilities in a global supply chain disruption or when the region experiences instability (World Bank, 2023). One of the ways out of this situation would be for Colombo to rely more on domestic industries to create self-sufficient supply chains. For instance, Sri Lankan textile manufacturers that contribute 40 percent of the country's apparel exports can switch to producing military uniforms and tactical gear to decrease reliance on foreign suppliers (Sri Lanka Export Development Board, 2023). Similarly, support from localized food production, can ensure reliable rationing for troops in times of emergency.

The 2022 economic crisis really underscore the vulnerabilities that the country would face when it depends on importing. It led to fuel shortages freezing up naval patrols and stranding air surveillance (World Bank, 2023). Public and private partnerships, then, could help develop a situation akin to "Make in India," whereby much of the domestic firms branched out into supplying militai-requirements within their area (Make in India, 2014).

2. Digital Transformation

a. Blockchain for Secure Inventory Tracking. Blockchain technology has the potential to transform and disrupt the military inventory systems of Sri Lanka, which are plagued by corruption and inefficiency. An example would be that of Ukraine employing blockchain to track Western support, a model that offers 99% audit accuracy (Marijan, 2023). A decentralized ledger would enable real-time tracking of arms stockpiles and fuel and medical supplies across bases in country.

b. AI for Predictive Maintenance of Equipment. The implementation of AI based predictive maintenance analogous to the U.S. Army's PdM 4.0 initiative, could work into and save Sri Lanka's aging naval fleet (Marijan, 2023). Sensors fitted on SLNS Sayurala (Offshore Patrol Vessel) could analyze engine wear and forecast possible failures before critical missions. Predictive algorithms could have also come into play during the 2022 fuel crisis by intelligently managing the very limited stock of diesel reserves to undertake essential patrols, thereby averting operational paralysis (Sri Lanka Ministry of Defence, 2022).

3. Multi-Domain Logistics

This needs integrated naval, air and ground logistics. Sri Lanka is seriously located in the Indian Ocean as a critical node for maritime trade globally (Irfan, 2023). Today, with infrastructure and coordination gaps addressed of the Trincomalee Port, it could be a multi-domain hub, similar to the Changi Naval Base in Singapore, with its natural deep-water harbor (Premarathna, 2021). Case in point, the X-Press Pearl incident of 2021, the lack of coordination between the Navy and coast guard greatly delayed containment actions, signifies dysfunctions in a broader system concerning crisis reposnse (Alkema and Melenchuk, 2022). Such a command at Trincomalee coordinated with all airbases and Army installations in the country would efficiently streamline hybrid threat responses such as drone incursions or smuggling circuits.

Distributed logistics would render much style lessons from the Indo-Pacific. Exercising with India in the Andaman and Nicobar Command, for instance, will assist in attaining such interoperability for resupplies to go fluently during any crisis as highlighted in the Indo-Pacific security paradigms (Premaratne and Thrishali, 2020).

4. Civilian Collaboration

The hybridization of warfare requires seamless cooperation between military innovators and civilian innovators, since conflicts are now being heavily influenced by non-state actors and technologies from the private sector (Hoffman, 2007). Startups such as Aeronation may have the means to adapt the commercial application of drones by employing them for reconnaissance support or supply drops for mountainous areas, much like Ukraine did with DJI Mavics for trench resupply of ammunition (Goncharuk, 2024; Bondar, 2024).

Engagements with private sector partners such as Dialog Axiata should yield dual-use solutions such as 5G networks for IoT sensors deployed on the battlefield or AI supported coastal surveillance and such partnerships ought to integrate civilian technology into defense systems, establishing a kind of framework for defense integration premised on India's paradigm of "Make in India" (Make in India Defense, 2014). It also supports Indo-Pacific strategies that seek interoperability (Premaratne and Thrishali, 2020). These partnerships have strategic significance in hybrid warfare contexts, as demonstrated by their use in Israel's Unit 81, which capitalizes on civilian innovations for defense (Deshpande, 2018).

Challenges and Mitigation

1. Resource Scarcity

Sri Lanka's reliance on imported fuel and ammunition, 85% of the military inventory, renders its defense logistics vulnerable to any global supply shock, as observed during the economic crisis of 2022 (World Bank, 2023). For increased resilience, a continent's approach to decentralized stockpiling as used by Ukraine in order to hide from Russian strikes could be beneficial for Sri Lanka (Alkema and Melenchuk, 2022). For instance, regional fuel depots in Jaffna, Trincomalee, and Galle would limit reliance on centralized depots in Colombo. Other alternatives could include diversification into energy sources, such as the use of biofuels when conducting naval patrols, thus insulating operations from price fluctuations.

2. Cybersecurity Risks

Sri Lanka's digital logistics infrastructure, from blockchain inventory systems to AI predictive maintenance, is vulnerable to state sponsored cyberattacks and ransomware. From Ukraine's experience, hybrid adversaries like Russia focus on logistics software to disrupt supply chains an ever-present danger given Sri Lanka's dated IT protocols (Marijan, 2024). With zero-trust cybersecurity architectures, as experimented with in Indo-Pacific joint exercises, being put in place, this would limit unauthorized access to critical systems such as the command center of Trincomalee Port (Georgetown Security Studies Review, 2024).

Engagement with firms such as Dialog Axiata could develop quantum-resistant encryption for secure data transmission, while AI guided anomaly detection systems could raise real-time alerts for potential breaches. Regular audits, based on NATO's transparency initiatives for Ukraine, would further strengthen defenses (Trif and Dumitrascu, 2025).

3. Political Constraints

Being neutral in international relations usually brings about problems where logistics partnerships can be weighed down by world powers. For instance, Sri Lanka needs to carry the grave risk of allowing its critical friends to feel sidelined, for example, by holding India's security concerns regarding the Chinese-sponsored Hambantota Port on one side (Premaratne and Thrishali, 2020). The way out could be for Colombo to adopt some sort of ASEAN like "hedging" strategy and pursue multilateral agreements while staying away from formal alliances, such as the newly formed Colombo Security Conclave.

Joint logistics frameworks involving humanitarian aid and disaster response with India's Andaman and Nicobar Command would mesh inter-state confidence building measures with maintaining a posture that is yet not perceived as militarization (Irfan, 2023). Further, Sri Lanka could use its IORA membership as leverage to solicit dual-use infrastructure funding through the EU for the purposes of upgrading Trincomalee for civil-military interoperability, for instance (Premarathna, 2021).

Conclusion

Digital transformation technologies such as blockchain for inventory transparency and AI for predictive maintenance address inefficiencies and cyber threats that hybrid warfare is prone to inflicting. These technologies have gained acceptance and have been tested in conflict zones such as Ukraine (Marijan, 2024; Goncharuk, 2024) and are meant to give results with the highest velocity in the decision making and resource allocation processes. An example is Trincomalee Port, envisioned as a multi domain hub, linking air with ground networks, emphasizing how strategic geography can make rapid response capabilities effective (Premarathna, 2021).

Decisions, policies, and principles must also be very agile. Non-alignment poses no hindrance to partnerships; participating in multilateral attempts like the Colombo Security Conclave helps in getting technology and funding while ensuring that sovereignty is not compromised (Premaratne and Thrishali, 2020).

In the end, Sri Lanka's adaptive logistics should find flexibility to be its paramount feature, a mixture of domestic capacity with external best practices. By diversifying investments into decentralized systems, dual use technologies, and interoperable alliances, the Indian Ocean centrality will evolve from a source of liability into a fortification of resilience for the island.

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NEARSHORING FOR RESILIENCE: REPOSITIONING SRI LANKA AS SOUTH ASIA'S LOGISTICS POWERHOUSE

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Abstract

Nearshoring has been a crucial tactic for boosting resilience, sustainability, and agility in response to the COVID-19 epidemic and geopolitical unrest that disrupted global supply chains. The potential of Sri Lanka to emerge as the premier nearshoring and logistics hub in South Asia is examined in this essay. Sri Lanka offers a competitive option to conventional outsourcing locations because of its advantageous maritime position, highly qualified and English-speaking workforce, investor-friendly regulations, and dedication to sustainable practices. The research lists Sri Lanka's benefits in important industries such as electronics, agribusiness, pharmaceuticals, IT and BPO services, and clothing manufacture. It also tackles policy and infrastructure barriers that can prevent this change. Strategic investments in workforce development, trade integration, digital infrastructure, and ESG compliance are suggested to increase Sri Lanka's attractiveness to international investors. In the end, this reorientation provides a timely chance to take the lead in developing robust supply chains and is consistent with Sri Lanka's aspirations for national progress and global regionalization trends.

Key Words: Nearshoring, supply chain resilience, investor friendly regulations, logistics hub

Introduction

In the wake of COVID-19, there was a significant shift in the global logistics and supply chain environment(Sarkis, 2021). Globally, businesses are reconsidering long-distance sourcing strategies and moving toward regional hubs that provide more strategic resilience, shorter transmission times, and increased predictability (Schabasser, no date). The COVID-19 pandemic, geopolitical tensions, and disruptions such as the Red Sea shipping crisis have highlighted the vulnerability of distant and complex supply chains (Notteboom, Haralambides and Cullinane, 2024). Nearshoring is the practice of relocating manufacturing or sourcing closer to the final market, a strategy that helps reduce risks, lower costs, and shorten lead times, especially in response to recent global disruptions.". Nearshoring offers Sri Lanka a country with a thriving garment and manufacturing industry and a strategic location in the Indian Ocean, the chance to develop into a regional center for logistics and manufacturing (Fernández-Miguel et al., 2022).

The Global Shift Toward Nearshoring

Offshoring has historically been the most common strategy used by businesses trying to reduce production costs by moving manufacturing to nations with lower labor expenses. But during the pandemic, which resulted in significant supply chain failures, shipping delays, and shortages of necessities, the model's weakness was made clear (Xu et al., 2020). As an example During the height of the pandemic in 2020, global shipping delays led to critical shortages of medical supplies and semiconductors, causing production halts in industries like automotive and electronics. The 2020 and 2021 disruptions exposed the weakness of global supply networks that mostly depended on distant suppliers or single sources (Kenneth and Pettersen, 2024). Companies are also being encouraged to localize production and increase supply chain transparency by new environmental, social, and governance (ESG) requirements (Waggoner, 2024). By providing regional manufacturing options to more established international suppliers like China, nations like Mexico, Poland, and Vietnam are already taking advantage of these trends (Nabeshima, no date).

Growing geopolitical insecurity is also having an impact on the global trend toward nearshoring. Businesses have been forced risks because of trade disputes, such as those between the United States and China has also been brought to light by the Russia-Ukraine conflict and the sanctions that have followed (Bishai, 2024). North American and European businesses are becoming more interested in nearshoring to regions like Latin America and Eastern Europe, respectively. For instance, because of its proximity, trade agreements like the USMCA, and comparatively lower labor costs, Mexico has emerged as a key beneficiary tactic. Poland, Romania, and the Czech Republic are among the nations in Europe that are becoming more and more appealing substitutes for conventional Asian suppliers (Canosa, 2024). The low-cost nations have decreased due to developments in automation, artificial intelligence, and digital supply chain platforms. The demand for ultra-cheap labor is decreasing as production becomes less labor-intensive, allowing businesses to place a higher priority on responsiveness and strategic location (Kamp and Gibaja, 2021).

Strategic Advantages of Sri Lanka for Nearshoring

Though historically disregarded in favor of more established regional firms, Sri Lanka is quickly becoming a very attractive nearshoring location, particularly for businesses looking for a flexible, affordable, and sustainable option in South Asia. The distinct strategic benefits that establish Sri Lanka as a nearshoring hub in the contemporary global supply chain ecosystem are highlighted in this essay (Basalat and Priyanka, 2024).

1. Strategic Maritime Location

Situated at the intersection of major shipping routes in the Indian Ocean, Sri Lanka is a natural logistics gateway between East and West, making its geographic location one of its most valuable nearshoring assets. The Port of Colombo is one of the busiest and most efficient transshipment hubs in South Asia, with direct access to over 80 ports worldwide. Its proximity to important global markets, including India, the Middle East, and Southeast Asia, allows for shorter transit times and lower freight costs, which are crucial advantages for businesses aiming for just-in-time delivery models (Students and Faculty, 2020).

2. Skilled Workforce with English Proficiency

With a solid educational background in engineering, textiles, information technology, and finance, Sri Lanka has a workforce that is highly trainable and literate. Notably, many of the language hurdles that are typical in other nearshoring destinations are removed because English is widely spoken and used in professional settings. Foreign operations across industries, including precision manufacturing, IT services, fashion, and business process outsourcing (BPO), benefit from the availability of a highly skilled workforce. This ensures that these operations can maintain high standards of quality without compromise (Falendra Kumar Sudan, 2023).

3. Competitive Costs and Intensives

Sri Lanka provides an attractive cost-to-value ratio, despite, not being the most affordable travel destination in the area. The cost of labor, infrastructure, and operations is still competitive when compared to neighboring ASEAN countries and far lower than in Europe or the Americas. More significantly, tax holidays, duty-free imports of capital equipment, and industrial zones with integrated manufacturing and logistics capabilities are only a few of the investor-friendly measures that the Sri Lankan government provides. For businesses wishing to launch low-risk near-shore operations, these regulations facilitate the shift (Sugathadasa, Perera and Liyanage, 2020).

4. Focus on Sustainability and Ethical Manufacturing

Particularly in the clothing industry, Sri Lanka has established itself as a pioneer in sustainable and ethical production. WARP, Fair Trade, and LEED certifications are frequently obtained by Sri Lankan exporters. This is in line with the rising demand for ecologically friendly sourcing from businesses and consumers. Businesses can use Sri Lanka's green manufacturing methods to improve their ESG profiles and adhere to international sustainability standards when they relocate there for nearshoring (Perry, Wood and Fernie, 2014).

5. Political stability and Trade access

Despite its political and economic difficulties, Sri Lanka's economy is still among the most open and democratic in South Asia. Sri Lanka provides a reasonably stable business climate with robust legal protections for foreign investments and a track record of keeping its trade promises. Its value proposition as a nearshoring partner is further strengthened by its preferential trade access to important countries, such as the EU (GSP+) and India (via the Indo–Sri Lanka Free Trade Agreement) (Gunasekara, 2021).

Nearshoring Opportunities in Key Sectors

1. Apparel and Textile Manufacturing

Sri Lanka's clothing industry is already a major force in the world, supplying high-end labels like Levi's, Nike, and Victoria's Secret. The nation has a major advantage in nearshoring because of its transition to sustainable and ethical manufacturing. Relocating production to Sri Lanka to be closer to key markets is a strategic decision driven by the need to reduce lead times and carbon footprints. The nation is known for its design-to-delivery skills, world-class compliance, and vertically integrated supply chains. Furthermore, a lot of Sri Lankan clothing producers make use of cutting-edge technology including automation, digital patternmaking, and 3D sampling. These solutions facilitate less waste and quicker turnaround, two important nearshoring strategy requirements. Furthermore, the nation has gateway access to more than 1.6 billion customers through its free trade agreements with Pakistan and India. In addition to its advantageous location in the global apparel supply chain, Sri Lanka is now being considered by brands seeking to de-risk operations from China or Central America (Susitha, 2022).

2. IT and Business Process Outsourcing

With over 30,000 IT professionals and an increasing number of graduates in software engineering, data analytics, and cybersecurity, as well as high English fluency and cultural alignment with Western markets, Sri Lanka has been attracting attention as a nearshoring hub for IT and BPO services. The cost of operation is significantly lower than in traditional markets like Eastern Europe or the Philippines, and the country is one of the top global destinations for knowledge process outsourcing (KPO) and finance & accounting services. Furthermore, dependable data infrastructure and adherence to international IT standards are the results of the government's emphasis on cybersecurity and digital transformation. Nearshoring IT activities to Sri Lanka can help businesses in the retail, healthcare, finance, and logistics sectors increase operational resilience, reduce costs, and increase agility. The government's emphasis on cybersecurity and digital transformation has also resulted in dependable data infrastructure and adherence to international IT standards. Businesses in the retail, healthcare, banking, and logistics sectors might gain from nearshoring their IT activities to Sri Lanka to increase operational resilience, reduce costs, and gain better agility (Harshani De Silva, 2018).

3. Electronics and Precision Manufacturing

Although Sri Lanka's electronics and precision manufacturing industry is still in its infancy, its expanding infrastructure and government assistance make it a compelling candidate for nearshoring. Businesses in the fields of medical devices, circuit board assembly, sensors, and automotive components are increasingly looking outside of East Asia. Specialized industrial parks designed for advanced manufacturing are available in Sri Lanka, such as the BOI Export Processing Zones. Manufacturers are looking for smaller, more adaptable. places like Sri Lanka that offer cost-effectiveness without sacrificing quality because of growing wages and geopolitical dangers in conventional hubs. Businesses seeking green manufacturing and traceability find the nation appealing due to its highly qualified engineering workforce and emphasis on clean energy. Additionally, its advantageous location close to Middle Eastern and Indian markets guarantees prompt distribution and lower shipping costs. The feasibility of nearshoring precision manufacturing to Sri Lanka is also being enhanced by investments in intelligent storage and logistics hubs (Susitha, 2022).

4. Agribusiness and Food processing

Sri Lanka is the perfect place for nearshoring in agriculture and food processing because of its lush land, tropical climate, and ancient agricultural heritage. Sri Lanka is in an excellent position to supply fruits, spices, herbs, tea, and items made from coconuts, as the demand for healthier and organic food products rises worldwide. The nation has already established a solid reputation for its cinnamon and Ceylon tea, and it is now diversifying into value-added exports such as organic spices, dehydrated fruits, herbal drinks, and prepared foods. Businesses can profit from low-cost raw ingredients, skilled rural labor, and proximity to Asian and Middle Eastern markets by outsourcing food processing to Sri Lanka. Its allure is increased by government subsidies for food tech businesses, agro-processing zones, and environmentally friendly agricultural methods. Sri Lanka's emphasis on international food safety standards (such as HACCP and ISO) also aids investors by facilitating quicker entry into the European and Gulf markets (Vladimir et al., 2024).

5. Pharmaceuticals and Life sciences

Sri Lanka is a potential site for nearshoring life sciences operations since it is growing its capacity to manufacture pharmaceuticals. In this area, the government is actively promoting public-private partnerships by providing pharmaceutical manufacturers with access to industrial parks and tax breaks. Strong university-level education in science and medicine, a highly literate populace, and an expanding pool of qualified researchers and pharmacists are all features of the nation. Pharmaceutical companies can effectively supply regional markets including Bangladesh, India, and the Maldives thanks to Sri Lanka's advantageous position. Additionally, nearshoring the production of necessary medications and healthcare products to stable nations like Sri

Lanka helps to improve supply security as supply chains grow increasingly susceptible to disruptions (such as during COVID-19). Sri Lanka is an affordable and legal partner for nearshore production for global businesses involved in clinical research, herbal medicine, and generics ('EVALUATING THE POTENTIAL OF RESHORING APIs TO STRENGTHEN PHARMACEUTICAL SUPPLY CHAIN RESILIENCE : AN EXPLORATORY', 2023).

6. Logistics and Maritime Services

Sri Lanka is an ideal location for logistics because the Port of Colombo is one of the busiest in South Asia. By outsourcing supply chain and logistics operations to Sri Lanka, businesses can access top-notch maritime infrastructure. The nation is ideally situated for regional distribution centers and transshipment hubs due to its strategic location at the intersection of important maritime routes between Asia, Europe, and the Middle East. Cargo handling capacities have been enhanced by recent improvements in ports like Hambantota and dry ports surrounding Colombo. Additionally, the government is promoting bonded warehousing, smart logistics, and customs digitization, all of which help businesses search for effective nearshore logistics sites. Because of its expertise in handling logistics for electronics, tea, and clothing, Sri Lanka is a reliable logistics partner for businesses looking to save freight costs and expedite deliveries (Hsu, Li and Wu, 2022).

Infrastructure and Policy Bottlenecks

Sri Lanka has a lot of potential as a nearshoring location, but its full potential is constrained by several legislative and infrastructure barriers. One of the main challenges is the outdated road network and inadequate railway connectivity between ports and inland industrial zones. Despite the great efficiency of the Port of Colombo, there is frequently insufficient road and rail connectivity between ports and inland industry zones, which causes delays and raises logistical costs. The lack of dependable electricity, internet, and storage facilities in rural locations, where many SMEs operate, limits the scalability of production (Weerakoon and Perera, 2018).

Long-term investment is deterred by bureaucratic red tape, delays in customs clearance, and frequent changes in trade regulations. Business confidence is impacted by the government's inconsistent implementation and lack of interagency collaboration, despite the introduction of various investor-friendly measures. Furthermore, Sri Lanka has a limited network of free trade agreements, which limits its ability to integrate with international supply chains despite its advantageous geographic location (Academy, no date).

Despite their protection, labor rules are occasionally viewed as inflexible, particularly when it comes to hiring flexibility and overtime. It is more difficult for businesses to expand their near-shore activities quickly due to these regulatory inefficiencies. Sri Lanka must make investments in updating its infrastructure and simplifying regulations to establish a stable, effective, and globally competitive business climate if it is to become a major hub for nearshoring (Abeysinghe and Abeyratne, 2016).

Strategic Interventions for Sri Lanka

Sri Lanka must carry out focused strategic interventions in the areas of infrastructure, policy, and workforce development if it wants to establish itself as a competitive nearshoring hub. First, it is crucial to invest in both physical and digital infrastructure. Supply chain activities will be more efficient if ports are connected better, logistics parks are expanded, and inland transportation is improved. Encouraging smart manufacturing and expanding broadband coverage will also draw tech-driven businesses. Second, the government ought to implement policies that are geared toward nearshoring, like tax holidays, expedited business registration, and streamlined customs processes. Sector-specific support and shared services can be provided via Special Economic Zones (SEZs) designed for certain industries, such as medicines, agro, and clothing. The third important factor is workforce development. Programs for upskilling in modern manufacturing, logistics management, and digital literacy can guarantee a consistent personnel pool. Training will be more in line with industry demands thanks to public-private collaborations between universities and vocational schools. Fourth, improving market access and drawing in additional investment can be achieved by fortifying regional economic links through bilateral and multilateral agreements (such as those with the EU, ASEAN, and India). Lastly, for Sri Lanka to attract businesses interested in ethical sourcing and environmentally friendly operations, sustainability and ESG compliance must be integrated into every industry (Weerabahu and Nanayakkara, 2015). With these improvements, Sri Lanka will become a dependable, robust, and progressive nearshoring location.

Environment and Sustainability Considerations

Sustainability must be at the forefront of this shift as Sri Lanka investigates nearshoring to increase its manufacturing and logistical capabilities. Green supply chains are becoming more and more in demand from international customers, and nations that don’t adhere to social and environmental norms risk losing foreign investment. As a result, including environmentally friendly logistics techniques is not only morally right but also calculated. Sri Lanka can take steps like investing in renewable energy for industrial parks, building energy-efficient warehouses, and electrifying its fleet of vehicles. Circular supply chain models, sustainable packaging, and waste reduction techniques can improve environmental compliance and financial effectiveness (Sector, 2019).

Respecting ESG (Environmental, Social, and Governance) principles will enhance the nation’s reputation in international marketplaces. Green building regulations, carbon reporting, and supply chain pollution control must all be supported by regulatory frameworks. Furthermore, sustainable planning is necessary to prevent environmental degradation because of Sri Lanka's biodiversity and delicate ecosystems. Careful management of coastal development is necessary to strike a balance between conservation and growth, particularly in the vicinity of ports. Sri Lanka ensures that industrial growth does not come at the expense of environmental health by incorporating sustainability into its nearshoring agenda, in addition to meeting international standards (Seenapatabendige, 2022).

Conclusion

In the wake of recent challenges, global economies are readjusting their supply chains, and nearshoring has become a key tactic for improving sustainability, agility, and resilience. This worldwide change presents Sri Lanka with a momentous and revolutionary chance to reestablish itself as the logistical hub of South Asia. Sri Lanka is ideally positioned to act as a nearshoring destination for regional and international markets due to its advantageous maritime location along important East-West shipping routes, its developed port infrastructure, including the Port of Colombo, and its history of export-oriented sectors like clothing.

By promoting value-added production, lowering reliance on far-off industrial centers, and drawing in foreign direct investment (FDI), nearshoring supports Sri Lanka's growth objectives. The nation's competitive advantage is further strengthened by its integration with rising African and South Asian markets through trade facilitation legislation and free trade agreements. To take advantage of this opportunity, though, aggressive policymaking, digital infrastructure investment, and ethical governance enhancements are needed. Stronger Special Economic Zones (SEZs) streamlined customs processes, and encouragement of green logistics are necessary to satisfy global businesses that need supply chains with greater traceability, cost-effectiveness, and turnaround times.

Furthermore, it will be crucial for Sri Lankan businesses to use digital tools including virtual private networks (VPNs), cloud-based inventory systems, and electronic data interchange (EDI). Particularly in industries like B2B apparel manufacturing, electronics, and intermediate component production, these technologies can enable regional SMEs to more successfully connect to global value chains.

However, there are obstacles in the way of progress. Investor confidence is nevertheless impacted by issues like foreign exchange volatility, skills shortages, energy insecurity, and political unpredictability. It will be crucial to address these problems by investing in infrastructure, developing the workforce, and reforming governance. To fully realize the benefits of nearshoring in Sri Lanka, cooperation between the public and business sectors would be required.

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SUB THEME 03

SUSTAINABLE LOGISTICS PRACTICES: INCORPORATING ENVIRONMENTAL RESPONSIBILTY INTO SUPPLY CHAINS

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THE EFFECTS OF LOGISTICS AND GREEN LOGISTICS PRACTICES ON INTERNATIONAL TRADE IN SOUTH ASIA: A COMPARATIVE ANALYSIS

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Abstract

The purpose of this paper is to examine the relationship between logistics performance and international trade of South Asia along with green logistics performance which is now a critical factor in determining the dynamics of regional trade in the modern world where there is a fast rate of globalization and growing environmental consciousness. The study uses an augmented gravity model which incorporates logistics and green logistics variables to examine the relationship of logistics performance and green logistics performance with South Asian international trade using data from 2007–2022. Furthermore, the effect of green logistics on international trade has been examined using a newly created green logistics performance index for the nations in this region. The feasible generalized least squares approach, fixed effects model, random effects model, and pooled ordinary least squares method were used to estimate the panel data set. The study's findings revealed that trade volume has a positive relationship with both exporting and importing nations' logistics performance indices. Additionally, exports and the green logistics performance of exporting nations are positively related. Conversely, green logistics performance of importing nations has a negative relation with the export volume of exporters. Policy makers are encouraged to invest in strategies that include cutting-edge technologies to enhance logistics performance. Green logistics practices should also be promoted to raise public awareness of the need to address environmental issues in South Asian economies.

Keywords: Export performance, gravity model, green logistics, international trade, logistics performance, South Asia

Introduction

International trade has been characterized as the "engine of growth" that propelled the development of today's economically developed nations in the late 19th and early 20th centuries (Edirisinghe, 2017). Increasing exports is one of the top concerns for every government striving to spur economic growth (Oo et al., 2019). Logistics is considered as one of the main factors affecting exporting procedures from production to delivery (Fernie and Sparks, 2018). According to the World Bank (2023), logistics is a network of services that facilitate the actual transportation of products across international borders. Since 2007, the World Bank has published the Logistics Performance Index

(LPI), which contains six components: the regularity with which shipments reach consignees, the skill and caliber of logistics services, the ease of arranging reasonably priced international shipments, the standard of trade and transport-related infrastructure, the efficiency of customs and border management clearance, and the ability to track and trace consignments (World Bank, 2023). Over the past few decades, there has been a major expansion in global trade; nevertheless, most developing countries have not kept up with this stage of development due to an inability to connect to global networks on a logistical basis (Tonguir et al., 2020). The relationship between LPI index values in 2022 and the world's top and bottom exporting nations is depicted in Figure 1.

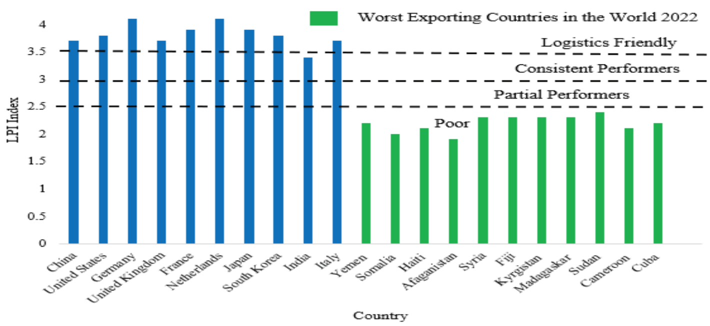

Figure 1: Relationship Between the Best and Worst Export Countries in the World and Their Lpi Values, 2022

Source: World Development Indicators, 2023, World Bank and World Factbook, 2024

Figure 1 shows that in 2022, the world's top exporting nations had the best logistics performance, while the world's bottom exporting nations had the lowest logistics performance and demonstrates that a nation's performance in the logistics sector has a significant role in its ability to rank among the top in international trade.

Particularly in recent years, climate change stands as the world's greatest challenge, and carbon emissions (CO_2) constitute the primary driver of global climate change (Karaduman et al., 2020). Because the logistics sector causes damage to the environment and produces greater levels of carbon emissions, implementing green logistics practices thus becomes potentially an imperative strategy in promoting international trade (Le et al., 2022). With the advent of global sustainable development in the 1980s, the idea of "Green Logistics" which encompasses a variety of sustainable strategies and methods to lessen the environmental impact of logistics operations has become more widely recognized (Huong et al., 2024). In 2023, the World Bank stated that integrating environmentally friendly practices that reduce CO_2 can improve logistic performance and contribute to minimizing risks to public health or the environment. According to the global emissions calculator, the transport and logistics industry produced around 24% of the world's CO_2 emissions in 2023. The European Environment Agency also predicts that by 2050, global logistics would account for 40% of the world's carbon emissions (Carbon Care Organization, 2024).

South Asia, the southern subregion of Asia, is home to 1.94 billion people as of 2023, making it the most populated geographical region in the world (World Bank, 2024). Nevertheless, due to a lack of trade facilitation measures, South Asian nations face high trade costs and a static position in the merchandised trade structure, with most of their competitors adopting a limited number of product baskets to compete in the export market (Kunroo and Ahmad, 2023). As a proportion of global merchandise exports, the Asian region accounts for 41.59%, while South Asia accounts for only 2.61% in 2023 (UN Trade and Development, 2024). In comparison to other regions across the globe, the average logistics performance in South Asia is relatively poorer (Alpaslanoglu, 2024), which is also witness in Figure 2.

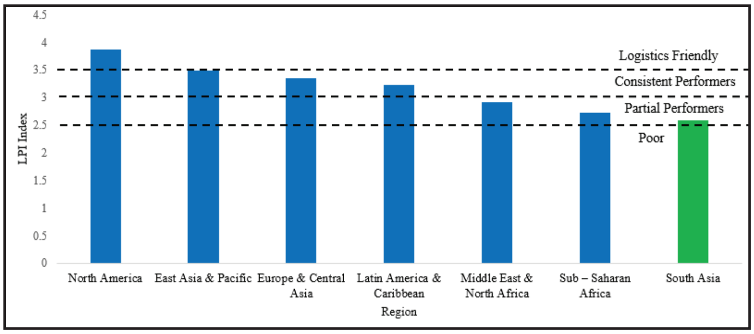

Figure 2: Average Logistic Performance Index (LPI) Scores of Global Regions, 2022
Source: Alpaslanoglu, 2024

As per the 2023 Vulnerability Index, which measures a nation's sensitivity, ability, and exposure to the effects of climate change, South Asia stands as the most susceptible region in the world. Furthermore, South Asia is more affected by natural catastrophes than any other region in the world, with an average of 60 million people affected annually (World Bank, 2024). In addition, South Asia accounts for over 9% of global annual CO_2 emissions in 2022, and the transportation sector accounts for approximately 11% of regional CO_2 emissions in the same year (Our World in Data, 2024). The South Asian region's yearly CO_2 emissions for the past ten years are shown in Figure 3, which indicates an increasing trend in the region's CO_2 emissions.

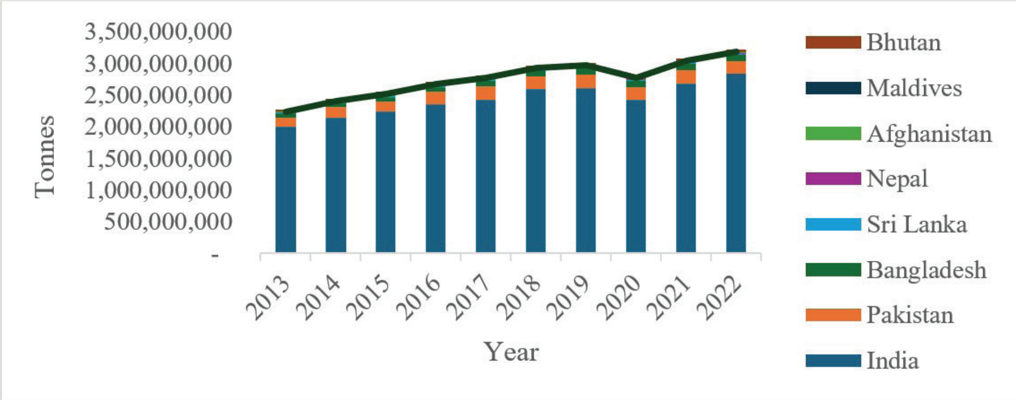

Figure 3: Annual CO_2 Emissions in South Asia, 2013-2022
Source: Our World in Data, 2024

Several studies (Kunroo and Ahmad, 2023; Malhotra and Kumari, 2016; Naseri et al., 2018) have been conducted in the South Asian context to determine the factors affecting export performance; however, the specific impact of logistics and green logistics practices on trade remains underexplored.

Methodology Aid Experimental Design

The study employs a quantitative research method to examine the relationship between logistics performance (LP) and international trade & green logistics performance (GLP) and international trade in South Asia. The Gravity model is used to assess the relative contributions to the bilateral export volumes of South Asian nations to their major trading partners.

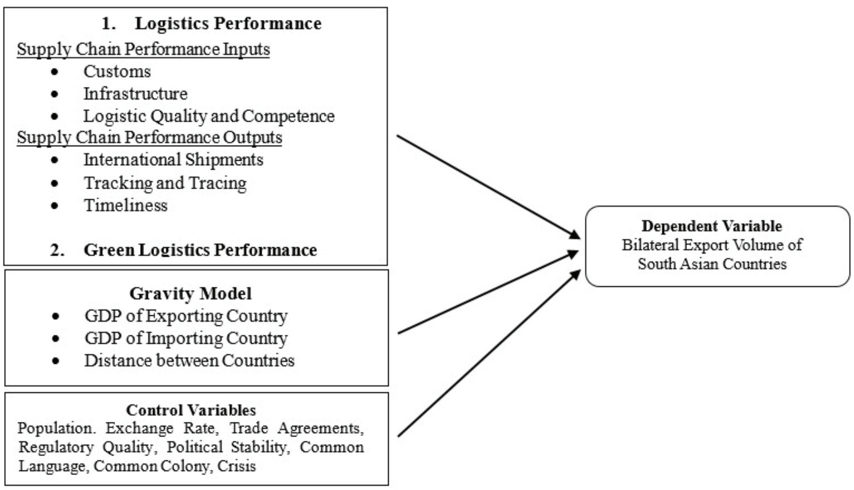

Figure 4: Conceptual Framework
Source: Compiled by authors

The study proposes a number of hypotheses to direct the investigation of the relationship between the variables that were selected.

Hypothesis 1: The logistics performance of the exporting country has a positive relationship with their export volume.

Hypothesis 2: The logistics performance of the importing country has a positive relationship with the export volume of the exporting country.

Hypothesis 3: The green logistics performance level of the exporting country has a positive relationship with their export volume.

Hypothesis 4: The green logistics performance level of the importing country has a negative relationship with the export volume of the exporting country.

The relationship between a nation's export performance and its logistics performance has been examined recently, and most of these studies are based on the gravity model (Sy et al., 2020; Takele and Buvik, 2015; Gani, 2017). It is well known among scholars that integrating several variables into the ordinary gravity model creates an augmented trade gravity model (Le, 2022). This study will also employ the augmented gravity model since several others have enhanced the simple gravity model by using control variables or dummy variables (Olyanga et al., 2022; Le et al., 2022).

This study will employ the Green Logistics Performance Index (GLPI) to measure the country's level of GLP. It aims to assess the nation's logistics performance while accounting for the environmental effects of all logistics operations. This ratio reflects the efficiency of input utilization in relation to the overall logistics performance and the resulting environmental impact. It can be expressed as follows:

$$GLPI = \frac{\text{Logistics Performance}}{\text{Environmental Impacts}}$$

To measure the GLPI, LPI can be used with Logistics CO2 emission (LCE), which illustrates how logistics have a negative impact on the environment. Accordingly, the above equation has been revised as follows:

$$GLPI_{it} = \frac{LPI_{it}}{LCE_{it}}$$

As a representation of LCE, the study used CO2 emissions from transportation (LCET), since transportation produces higher logistical carbon emissions, which is shown as;

$$GLPI_{it} = \frac{LPI_{it}}{LCET_{it}}$$

The environmental performance of logistics operations cannot be adequately described by using LCET alone because different countries have varying levels of economic development, which influence their logistics efficiency and environmental impact (Lu et al., 2019). To address this disparity, the study incorporates LCET per unit of GDP to examine logistics' CO_2 emission intensity (LCI), allowing a reasonable comparison of logistics-related CO_2 emission across economies with different sizes and development stages.

$$LCI_{it} = \frac{LCET_{it}}{GDP_{it}}$$

Finally, the GLPI calculation which reflects the green logistics performance level of a country can be mentioned as the ratio of the LPI and the logistics CO_2 intensity.

$$GLPI_{it} = \frac{LPI_{it}}{LCI_{it}} \quad \text{or} \quad GLPI_{it} = \frac{LPI_{it}}{(LCET/GDP)_{it}}$$

First, the following equation is used in the study to evaluate how logistic performance is related with international trade.

$$\begin{aligned} LnExp_{ijt} = {} & \beta0 + \beta1LnGDP_{it} + \beta2LnGDP_{jt} + \beta3LnLPI_{it} + \beta4LnLPI_{jt} + \beta5LnD_{ij} \\ & + \beta6LnPOP_{it} + \beta7LnPOP_{jt} + \beta8RQ_{jt} + \beta9PS_{jt} + \beta10LnER_{ijt} + \beta11CRI_{jt} \\ & + \beta8RTA_{ijt} + \beta9Lang_{ijt} + \beta10Col_{ijt} + \varepsilon i\, j\, t \end{aligned}$$

Second, the following formula is used to assess how green logistics performance is related with international trade, which is the primary objective of the study.

$$\begin{aligned} LnExp_{ijt} = {} & \beta0 + \beta1LnGDP_{it} + \beta2LnGDP_{jt} + \beta3LnGLPI_{it} + \beta4LnGLPI_{jt} + \beta5LnD_{ij} \\ & + \beta6LnPOP_{it} + \beta7LnPOP_{jt} + \beta8RQ_{jt} + \beta9PS_{jt} + \beta10LnER_{ijt} + \beta11CRI_{jt} \\ & + \beta8RTA_{ijt} + \beta9Lang_{ijt} + \beta10Col_{ijt} + \varepsilon i\, j\, t \end{aligned}$$

Expijt = The export volume from country i to country j at year t
GDPt = The GDP values of exporting (GDPit) and importing country (GDPjt) at year t
LPIt = Logistics performance Index of exporting (LPIit) and importing (LPI jt) country at year t
GLPIt = Green Logistics Performance Index of exporting (GLPIit) and import ing (GLPIjt) country at year t
Dij = Distance between the capitals of exporting and importing countries
POPt = Population of exporting country i (POPit) and importing country j (POPjt) at time t

RQjt = Regulatory quality level of importing country
PSjt = Political stability level of importing country
ERijt = Annual bilateral exchange rate (LCU of country i per LCU of country j) in year t
CRIjt = Dummy variables: value of 1 if existed a crisis in importing country at time t, 0 otherwise (Banking, Systematic, Currency, Inflation or Covid pandemic were considered)
RTAijt = Dummy variables: value of 1 if these two countries are members of any regional trade agreement at time t, 0 otherwise
Langijt = Dummy variables: value of 1 if exporting and importing countries share a common language, 0 otherwise
Colijt = Dummy variables: value of 1 if exporting and importing country have common colony heritage, 0 otherwise

The most suitable data type to test the gravity model is panel data (Le, 2022). India, Bangladesh, Pakistan, and Sri Lanka are the only four major South Asian nations that have been included as part of this study. This is because, taken as a group, those nations contributed approximately 99% of South Asian exports to the global economy (World Bank, 2024). The study considers over 30 destinations, which account for over 75% of South Asian exports, in order to ascertain the region's trade flows.

Results

The suggested models were tested using various estimating techniques: Pooled Ordinary Least Square (POLS) method, Random Effect model (REM), Fixed Effect model (FEM), Feasible Generalized Least Square (FGLS) method and Poison Pseudo Maximum Likelihood (PPML) method. The findings are shown in Table 1 for equation 1 and Table 2 for equation 2.

Variable	POLS	RE	FE	FGLS	PPML
$LnGDP_{jt}$	0.6183084***	0.7213196***	0.6293464***	0.607628***	0.6521641***
LnD_{ij}	0.1870123*	0.0612164	*(Omitted)*	0.2390842***	-0.0637855
$LnLPI_{it}$	4.598935***	1.418339***	0.5598093	3.923332***	2.79144***
$LnLPI_{jt}$	4.124737***	0.7088543***	0.5649177***	2.437136***	2.451614***
$LnPOP_{it}$	0.6691997***	0.8708114***	2.465884***	0.7345884***	0.9371475***
$LnER_{ijt}$	-0.0044346	0.0690191**	-0.0508624	0.0227694*	-0.0375702
RQ_{jt}	-0.2246958**	-0.1271636	-0.1033193	-0.1156773	-0.2651243
PS_{jt}	-0.3526336***	-0.0576928	-0.0392802	-0.399160***	-0.2130053*
CRI_{jt}	0.2473578***	0.0962261**	0.0644736**	0.1692413***	-0.0214986
RTA_{ijt}	-0.321953***	0.1127243	0.2183418*	-0.331255***	-0.597612***
$Lang_{ijt}$	-0.2157123*	-0.2115566	*(Omitted)*	-0.189825***	0.2912382
Col_{ijt}	1.177772***	1.012015***	*(Omitted)*	1.271114***	2.040828***
Constant	-24.02254***	-21.79059***	-47.9779***	-23.0146***	-23.4638***
R-squared	0.7425	0.6969	0.5670	NA	0.81463761
Adjusted R^2	0.7383	0.6969	0.5670	NA	
Prob > F	0.0000	0.0000	0.0000	0.0000	
Observations	750	750	750	750	

	P Value
Breusch and Pagan LM Test	0.0000
Hausman Test	0.0000
Wald Test	0.0000
Wooldridge Test	0.2054

Table 1 : The Impact of the Relationship Between LPI and International Trade in South Asia

Source: Author's calculation. *p<0.1; **p<0.05; ***p<0.01

At first, the POLS method was used to estimate equation 1. The second step was to estimate the REM. Random effects are present in the model when the P value is zero. The relevance of the POLS and REM was then determined using the Breusch and Pagan LM test. The Breusch Pagan Test's P value is zero, suggesting that the REM is superior to the POLS approach. After that, the FEM was estimated to determine if fixed effects were existent. The presence of fixed effects is indicated by a P value of zero. FEM and REM were then selected using the Hausman test. The model's P value is zero according to the Hausman test. The FEM is therefore preferred over the REM. According to the Hausman and Breusch Pagan tests, the FEM outperforms the REM and the POLS method. The model's econometric problems were further identified through technical tests, as determining autocorrelation and heteroskedasticity is important for establishing the statistical significance of the model. The Wald test revealed heteroskedasticity, and the test findings show that the model has heteroscedasticity which is corrected using the FGLS approach. The model was then examined for autocorrelation using the Wooldridge test, and the findings indicated that autocorrelation was absent.

Variable	POLS	RE	FE	FGLS	PPML
$LnGDP_{it}$	1.012064***	0.5836147***	0.6546545***	0.810066***	0.8075027***
$LnGDP_{jt}$	0.6803723***	0.5465291***	0.4695479***	0.6649791***	0.7145524***
LnD_{ij}	-0.1844945*	0.14139	*(Omitted)*	-0.0823263	-0.3170825
$LnGLPI_{it}$	0.4896008***	-0.2188164	-0.2665153	0.2662392**	0.6924548***
$LnGLPI_{jt}$	-0.641914***	0.0059064	0.259545	-0.2402431**	-0.457676***
$LnPOP_{it}$	0.0018997	0.3762274***	-0.231625	0.188160***	0.3280642**
$LnER_{ijt}$	0.0345554*	0.0644354*	0.0482011	0.0484141***	-0.0082534
RQ_{jt}	0.3678307***	-0.0220562	-0.1275034	0.2627902***	0.1066646
PS_{jt}	-0.0756847	0.0091719	-0.0256202	-0.140042***	-0.0425236
CRI_{jt}	0.1812431**	0.0912251***	0.0944958***	0.1399585***	0.0296322
RTA_{ijt}	-0.1811906*	0.0710551	0.2712166**	-0.1014375	-0.477366***
$Lang_{ijt}$	-0.2826897**	-0.2854653	*(Omitted)*	-0.1668293**	0.1799984
Col_{ijt}	0.9635982***	0.8660277***	*(Omitted)*	1.097061***	1.912445***
Constant	-19.64908***	-18.238***	-5.207368	-19.74801***	-20.5792***
R-squared	0.7496	0.7209	0.5775	NA	0.83564513
Adjusted R-squared	0.7452	0.7209	0.5775	NA	
Prob > F	0.0000	0.0000	0.0000	0.0000	
Number of observations	750	750	750	750	

	P Value
Breusch and Pagan LM Test	0.0000
Hausman Test	0.0000
Wald Test	0.0000
Wooldridge Test	0.1532

Table 2: The Impact of the Relationship between Green Logistic Performance and International Trade in South Asia

Source: Author's calculation. *p<0.1; **p<0.05; ***p<0.01

Then, similar to equation 1, the model selection and technical testing were conducted for equation 2. The Breusch Pagan LM and Hausman results in Table 2 show that the FEM is more appropriate than the POLS and RE approaches. The Wald and Wooldridge test results therefore indicate that the model has a heteroskedasticity problem. Consequently, it was fixed by employing the FGLS method.

An alternate estimate for gravity model that produces robust estimates even in the presence of heteroskedasticity, the PPML method, is used to compare the initial results with the other estimating methods.

The study's two main variables, LnLPIit and LnLPIjt, both have positive coefficients, and this finding is significant at the 1% level. This indicates that an exporting nation's LPI significantly and favorably affects the volume of exports. Thus, Hypothesis 1 can be accepted. Additionally, the export volume of exporting countries is significantly and positively influenced by the LPI of importing countries. The 2nd hypothesis is also then confirmed. Furthermore, the LPI coefficient of exporting nations is greater than that of importing nations, suggesting that the exporting nation's LPI has a bigger influence on export volume than the importing nations. Further, when the exporting and importing country increases its LPI by 1%, the export volume of the exporting country increases by 3.92% and 2.44% respectively when the other factors being held constant.

The findings demonstrate that exporting countries' green logistics performance is positively related to export volume, with the GLPI of these countries having a positive coefficient which is statistically significant at 5%. It implies that a greater export volume is produced by exporting nations with better green logistics standards. In particular, the LnGLPIit coefficient of 0.2662 shows that, when all other parameters are held constant, the exporting nation's export volume rises by 0.27% for every 1% increase in its green logistics performance level. Thus, Hypothesis 3 can be accepted. The importing nations' GLPI coefficient, on the other hand, is negative and statistically significant at 5%. As a result, it shows a negative correlation with export volume, signifying that increased green logistics performance in importing countries results in lower export volumes from exporting countries. Furthermore, according to the LnGLPIjt coefficient, which is -0.2402, a 1% increase in the importing country's green logistics performance level results in a 0.24% decrease in the exporting country's export volume. Because exporters' export volumes are reduced as a result of new green trade barriers created by the importing countries' environmental regulations (Wang et al., 2018). Consequently, Hypothesis 4 can also be accepted.

Furthermore, the research findings highlight that both traditional and green logistics performance complement each other in improving South Asia's trade performance. The GLPI's notable positive relationship also indicates its ability to help raise export volume, even though the LPI's significant coefficient emphasizes its immediate impact to do so. Therefore, South Asia's export performance can be maximized by taking a balanced approach that gives equal weight to improving logistics performance and green logistics performance.

Discussion and Conclusion

The New Trade Theory (Krugman, 1979) emphasizes the need of improving economies of scale in enhancing trade flows. Olyanga et al. (2022) proposed that a nation can exchange greater quantities of goods at lower costs if it improves its logistical infrastructure. By demonstrating that both the LPI of importing and exporting nations have a positive relationship with export volume, the study's findings complement this theory. Celebi (2019), Marti et al. (2014), Chakraborty and Mukherjee (2016), Gani

(2017), and Puertas et al. (2014) have all observed similar findings. The findings of the present study also show that the effect of the LPI on trade for exporting nations is greater than the effect on importing nations. The research conducted by Puertas et al. (2014) is consistent with this finding.

According to Grossman and Krueger's (1995) Environmental Kuznets Curve, economic development has a negative impact on the environment until a certain point, at which time it starts to improve. Furthermore, according to Porter's Hypothesis (Porter and Van der Linde, 1995), stringent environmental laws might spur innovation by compelling businesses to adopt more environmentally friendly forms of operation. These theories can also be applied to the trade logistics industry since, while building a logistics sector may initially result in harmful emissions, investing in green practices may lead to further development and improved environmental sustainability, which in turn may improve trade performance. These theories are supported by the study's findings, which demonstrate that exporting countries' export volumes increase with their green logistics level and that importing countries' export volumes decrease with their green logistics performance. Wang et al. (2018), Le et al. (2022), Huong et al. (2024), Fan et al. (2022), and Tran (2024) have all been found to concur with these findings.

The following policy recommendations ought to be taken into consideration in light of the results of the empirical investigation. Improving logistics infrastructure, encouraging superior logistics services, and incorporating cutting-edge IT systems should be top priorities for governments and exporters looking to improve logistics performance. Additionally, establishing targeted education and training programs for human resources is significant for boosting custom efficiency and enabling efficient logistics tracking capabilities. By enforcing appropriate environmental standards, governments can also play a significant role in promoting green logistics. Such regulations ought to foster an atmosphere that encourages the use of renewable energy sources in sustainable logistics practices in an effort to lower carbon emissions. Additionally, raising public awareness of green logistics is crucial. Moreover, businesses who use detrimental logistical techniques may be subject to environmental penalties or fines from the government. In addition, exporters should be concerned about conducting their logistics-related business operations through eco-friendly methods.

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BALANCING ENVIRONMENTAL RESPONSIBILITY WITH ECONOMIC VIABILITY AND SOCIAL EQUITY IN SRI LANKA'S SUSTAINABLE LOGISTICS PRACTICES

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Abstract

Logistics sector of Sri Lanka has advanced in environmental and social sustainability but struggles to integrate economic sustainability, creating an imbalance in Triple Bottom Line (TBL) adoption. This study investigates the barriers, financial constraints, infrastructure gaps, policy weaknesses, and technological limitations through a theoretical lens (TBL, NRBV, Dynamic Capabilities, and Circular Economy) and empirical analysis of Sri Lankan policies (e.g., NEAP 2022- 2030), case studies (e.g., Adani Wind Power withdrawal, tea industry practices), and industry reports. Findings reveal systemic trade-offs, such as stalled renewable projects due to cost-environment conflicts, while green initiatives (e.g., tea exports' 20% cost savings) lack robust economic metrics in sustainability reporting. The study proposes actionable solutions: green financing, public-private partnerships, Industry 5.0 adoption, and standardized economic performance reporting. By aligning environmental and social goals with economic viability, this research offers a framework for resilient, sustainable logistics in developing economies like Sri Lanka.

Keywords: Sustainable logistics, Triple Bottom Line (TBL), Circular Economy (CE), economic sustainability

Introduction

Global logistics operations and supply chain management have made sustainability their essential theme because businesses experience escalating pressure to harmonise their practices with environmental goals alongside social development and economic development targets. The TBL framework from Elkington 1997 stands as a universal definition of sustainability since it promotes the balance between environmental accountability and economic stability, and social fairness. Sri Lanka, together with other developing nations, prioritises sustainability measures in logistics through environmental protection and social welfare programmes while giving limited attention to economic considerations (ESCAP, 2022).

National economic growth in Sri Lanka depends heavily on logistics operations because the nation utilises strategic positioning and exports tea and apparel, and rubber products (Medani et al., 2024). The importance of the logistics sector cannot be understated, but it continues to experience obstacles when trying to implement economic sustainability within its operational strategies. The logistical sector in Sri Lanka faces barriers toward achieving sustainability balance due to outdated infrastructure alongside restricted technology adoption, high operational expenses together with weak policy enforcement requirements (ESCAP, 2022).

The National Environmental Action Plan (NEAP) 2022-2030, alongside other current Sri Lankan sustainability initiatives, focuses on environmental conservation together with biodiversity protection and social welfare improvement (Ministry of Environment, 2022). The sustainable achievements will be secured when environmental targets integrate fully with the economy's financial stability and business success.

The analysis assesses sustainable logistics management in Sri Lanka by examining the underdeveloped economic aspects. This research applies the TBL framework and the Natural Resource-Based View (NRBV) together with Dynamic Capabilities alongside Circular Economy models to interpret Sri Lankan practical situations. This paper seeks to establish evidence-based strategies which promote an integrated solution between environmental responsibility, economic viability, and social equity to build sustainable development and resilience for Sri Lanka's logistics sector.

Literature Review

Sustainability in logistics stems from the Triple Bottom Line (TBL) framework Elkington (1997) developed, which combines environmental with social and economic business aspects. Sri Lanka, as a developing country, demonstrates an excessive interest in environmental and social sustainability while showing limited attention to economic sustainability according to Dissanayake et al. (2016).

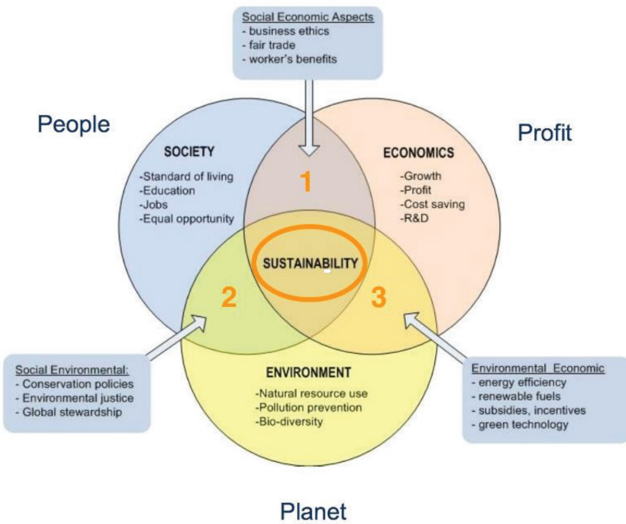

Figure 1: Triple Bottom Line (TBL)
Source: (Elkington, 1997)

Research by Hart (1995) demonstrates that the Natural Resource-Based View (NRBV) represents a vital method to build sustainability into competitive benefit for businesses. The logistics sector implements the Natural Resource-Based View theory to demonstrate how environmentally sustainable solutions, which reduce energy use or waste generation, actually lead to operational effectiveness with economic rewards. The economic possibilities of sustainable practices in Sri Lanka remain unfulfilled because of limited financial capabilities combined with inadequate infrastructure (ESCAP, 2022).

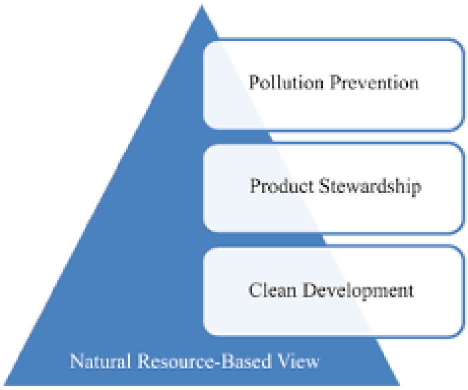

Figure 2: Natural Resource-Based View (NRBV)
Source: (Hart, 1997)

Dynamic Capabilities Theory, which Teece et al. (1997) developed, explains why organizations need adaptive strategies as protection in unpredictable business conditions. Logistics operations in Sri Lanka must invest in technological innovation together with digital transformation alongside green supply chain management to reach their sustainable economic and environmental targets.

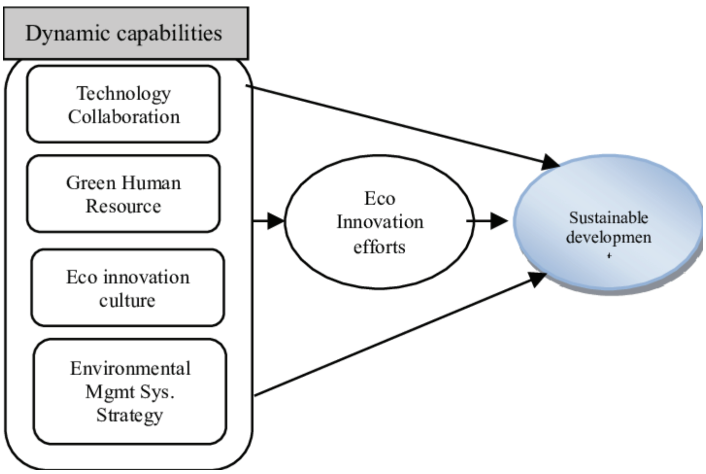

Figure 3: Dynamic Capabilities Theory
Source: (Teece et al., 1997)

The Circular Economy (CE) model has become a leading sustainable logistics approach dedicated to waste reduction and optimum resource utilisation and value production (Jayarathna et al., 2022). Research shows that CE adoption in Sri Lanka stands at a basic level because of insufficient governance structures and limited funding.

Figure 4: The Circular Economy (CE)
Source: (Jayarathna et al., 2022)

Sri Lankan companies primarily disclose environmental and social sustainability information in their reports, but they do not present economic metrics that demonstrate cost reduction or ROI from their sustainability initiatives (Dissanayake et al., 2016). The current deficiency represents an urgent requirement for developing sustainability models which incorporate economic outcomes when logistics companies operate in Sri Lanka. The Sri Lankan logistics sector functions as a fundamental element that enables international trade, partnered with the support of export activities, while creating links between regional and worldwide supply networks. Environmental protection and social welfare initiatives control sustainable logistics practices in Sri Lanka today, though economic viability remains less prominent (ESCAP, 2022).

The National Environmental Action Plan (NEAP) 2022-2030 presents complete strategies to fight environmental decay and uplift biodiversity alongside climate change risk reduction for logistics and transportation sections (Ministry of Environment, 2022). The strategies focus on rear tyre emission cuts from transportation alongside renewable energy system adoption and waste management system improvements. The implementation of these sustainability goals proceeds without a complete examination of their future economic impact.

The Sri Lankan tea export industry maintains Green Supply Chain Management strategies which target energy conservation and resource reduction in its operations (Medani et al., 2024). The industry deals with obstacles, including world market price uncertainties and expensive operation costs and climate-dependent threats that endanger its long-term economic viability.

The freight transport sector throughout Sri Lanka is plagued by old infrastructure combined with its dependency on imported fossil fuels while lacking proper integration of multimodal transport systems (ESCAP, 2022). The current transportation problems lead to higher logistics expenses and limit the growth of sustainable economic transport systems capable of supporting economic growth.

Sri Lanka's logistics sector demonstrates weak integration of economic performance metrics during sustainability reporting since most reports focus on environmental and social indicators (Dissanayake et al., 2016).

The present condition reveals that Sri Lanka needs to adopt a sustainable logistic approach which protects nature and supports social welfare together with operational efficiency and financial stability.

Challenges in Balancing Environmental, Economic and Social Goals

The logistics sector of Sri Lanka has dedicated numerous resources to environmental and social sustainability yet faces challenges in achieving a full economic sustainability balance. Multiple interconnected obstacles make achieving this process difficult.

1. Financial Constraints and Limited Green Financing

The high expenses related to environmentally sustainable practices represent the most significant barrier for Sri Lankan logistics firms in their sustainability efforts. Companies confront difficulty when they seek funding for renewable energy and energy-efficient transportation, and green infrastructure because such investments demand costly initial financing and green financing options are seldom available, according to ESCAP (2022). Private sector commitment to sustainable logistics practices remains low because there are no available financial aids or government assistance.

2. Policy Implementation and Governance Gaps

The National Environmental Action Plan (NEAP) 2022-2030 of Sri Lanka establishes environmental conservation strategies yet fails to properly enforce sustainability initiatives that use economic performance assessments (Ministry of Environment, 2022). Weak public-private coordination and poor institutional capabilities act together to worsen the country's governance system.

3. Infrastructure Deficiencies

The current logistics framework of Sri Lanka consists of outdated facilities which fail to achieve sustainable operations through modern technological capabilities. Road freight transportation provides the backbone to logistics performance, although the country faces road congestion problems and infrastructure decay alongside suboptimal road efficiency (ESCAP, 2022). Lack of advanced multimodal transport systems prevents Sri Lanka from using cost-optimised logistical solutions that are environmentally sustainable.

4. Technological Limitations

Low implementation rates of Industry 5.0 technologies, including Artificial Intelligence (AI), Smart Warehousing, Blockchain and Internet of Things (IoT), exist in Sri Lanka's logistics sector because of high costs and skills shortage gaps (Doluweera, 2024). The rejection of emerging technologies blocks logistics firms from their operational efficiency while preventing economic sustainability.

5. Environmental versus Economic Trade-offs

The Adani Wind Power Project, alongside other recent development initiatives, had to implement project withdrawal because environmental opposition combined with operational performance difficulties (Al Jazeera, 2024). Such delays demonstrate a major issue across Sri Lanka, where environmental concerns stop or postpone projects that create economic value due to the difficulty of managing money and nature simultaneously.

Practical Evidence: Case Studies from Sri Lanka

Sri Lanka demonstrates real-life scenarios which show how industries deal with environmental sustainability alongside economic success in their sustainable logistics operations.

1. Adani Wind Power Project Withdrawal

Indian company Adani Group pulled out from investing USD 442 million in the Mannar and Pooneryn wind power projects of Sri Lanka (Al Jazeera, 2024). Locals strongly opposed the renewable energy project because of their fears about migratory bird populations, while the project pursued its substantial renewable energy objectives to fulfil environmental sustainability targets (Climate Fact Cheques, 2024). The project experienced failure because of its financial stability issues combined with problems related to governance. Business development activities in Sri Lanka show constant tensions between sustainable environmental care and market growth objectives throughout the sustainability framework.

2. Tea Export Sector Green Practices

The tea export industry of Sri Lanka leads all sectors in implementing Green Supply Chain Management (GSCM) practices. The tea export industry focuses on waste minimization combined with energy-efficient transportation and ethical sourcing practices to reduce its environmental footprint (Medani et al., 2024). Such sustainable practices lead to cost reductions that reach levels up to 20% in operating expenses. The sector faces external financial sustainability challenges because of worldwide market price instabilities coupled with increased production expenses and changing climate conditions.

3. Sustainable Freight Transport Strategy 2030

The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) presented the Sustainable Freight Transport Strategy 2030 for Sri Lanka to establish integrated freight planning (ESCAP, 2022). Slow practical implementation has become an issue because of insufficient infrastructure alongside financial obstacles.

4. ESG Reporting Practices

Sri Lankan businesses mainly focus sustainability reports on environmental and social measures but integrate only minimal financial economic data regarding cost efficiency of green initiatives or Return on Investment (ROI) (Dissanayake et al., 2016). A lack of transparency inhibits the evaluation process for genuine economic advantages of sustainable logistics practices.

Recommendations

The implementation of sustainability in Sri Lanka's logistics sector requires maintaining equal importance among environmental responsibility and economic viability, and social equity. The strategic recommendations that follow derive from both theoretical models and practical implementation evidence.

1. Strengthen Green Financing Mechanisms

The Sri Lankan government needs to establish purpose-built financial programmes that help promote sustainable logistics projects. The government should provide economic benefits to logistics companies through green bonds together with low-rate funding and tax breaks that support their implementation of sustainable technologies and renewable solutions (ESCAP, 2022). The provided financial help enables firms to enter sustainable practices through reduced initial costs.

2. Promote Public-Private Partnerships

Government entities should establish programmes to motivate Public-Private Partnerships that help address infrastructure development challenges. The government, together with private sector entities and international organisations, can develop smart logistics hubs and integrated transport systems and renewable energy projects through collaborative ventures which support environmental as well as economic sustainability (Ministry of Environment, 2022).

3. Speedy Technological Adoption and Industry 5.0 Integration

Industry 5.0 investments in technologies such as Artificial Intelligence (AI) and Blockchain will help logistics firms improve their operational efficiency and environmental performance and reduce costs (Doluweera, 2024). The same benefits also apply to Smart Warehousing and Internet of Things (IoT) technology implementations. The sector requires workforce digital skill programmes to fill existing skill gaps among personnel.

4. Integrate Economic Metrics and Sustainability Reporting

The law should require sustainability reporting to contain economic performance information. Sustainability reports should incorporate financial metrics for green practice cost efficiency and ROI calculations, along with measures that demonstrate organisational financial resistance (Dissanayake et al., 2016).

5. Sustainable Freight Transport Strategy 2030

The ESCAP Sustainable Freight Transport Strategy 2030 requires operational implementation to develop infrastructure and minimise dependency on fuel and merge different transport initiatives (ESCAP, 2022). Sustainability management through this strategy will assist economic growth and environmental protection among logistics operations.

Conclusion

The focus on sustainable logistics practices in Sri Lanka involves active protection of the environment together with social equity improvement. Research into literature and field evidence exposes a crucial failure in merging economic sustainability with sustainability standards.

The National Environmental Action Plan (NEAP) 2022-2030 and Sustainable Freight Transport Strategy 2030 outline environmental and social sustainability policies, yet financial systems together with infrastructure development remain poorly developed. The Adani Wind Power Project withdrawal, together with green practices in tea export, demonstrates how environmental responsibility meets different economic thresholds in practical settings.

Sri Lanka's logistics sector requires a change from environmental-focused strategies to implement both economic resilience and social inclusiveness for long-term sustainability. To advance logistics sustainability, the sector needs improved green financial support and coordinated public- private initiatives, together with Industry 5.0 innovations and economic sustainability measures for reporting needs implementation.

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SUSTAINABLE LOGISTICS PRACTICES: INCORPORATING ENVIRONMENTAL RESPONSIBILITIES INTO THE SUPPLY CHAIN

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Abstract

Sustainable logistics integrates environmental responsibility into supply chain operations to save the environment by minimizing ecological footprints without diminishing efficiency. Due to increasing international supply chains, they contribute substantially to carbon footprints, extraction of natural resources and generation of waste. Key environment problems associated with logistics include high fuel consumption, greenhouse gas emissions, excessive packaging waste and ineffective transportation systems (Yedilbayev, 2023). Applying sustainable logistics solutions, such as waste reduction, power-saving warehouses, green transportation and the use of green products, is necessary to lessen these challenges. Implementing these practices has multiple advantages, like cost savings, regulatory complains, improved reputation, and overall long-term sustainability. Companies and organizations spend more on alternate fuels, electric vehicles, and route optimization for reducing carbon emissions levels. Digitalization and high-tech track systems increase productivity with less wastage. Successful collaboration among various stakeholders, supportive policies, and continuous innovation help sustainable logistics succeed. By implementing these sustainable logistics practices, companies and organizations are able to contribute towards global sustainability efforts without losing their market competitiveness.

Keywords: Sustainable logistics, green transportation, eco friendly packaging, carbon emission, circular economy

Introduction

Sustainable logistics is the integration of environmental, social, and economic considerations into planning, implementation, and supply chain activity management. It aims to reduce the environmental impact of logistics activities while maximizing efficiency and cost savings. In modern supply chains, where global trade and transport networks are expanding exponentially, the need for sustainable logistics has never been greater. As companies are increasingly being pushed by governments, consumers, and stakeholders to go green, incorporating sustainability into logistics operations has become a competitive advantage to a necessity.

The incorporation of environmental responsibilities into logistics is essential to reducing carbon gas emissions, minimizing waste, and conserving natural resources. Conventional practices of logistics, such as fossil fuel, excessive packaging, and inefficient routes, contribute heavily to global pollution and climate change (Veena Grover, 2024). Through the practice of sustainable logistics, companies are able to minimize carbon footprints, optimize the utilization of energy, and meet environmental regulations. Sustainable logistics also supports CSR, enhances corporate image, and saves costs in the long term by optimizing resource utilization.

Several significant key strategies can be adopted to achieve sustainability in logistics. They are green transport, which requires the use of fuel-efficient vehicles, electric vehicles, and alternative fuels; eco-friendly packaging, which avoids waste and promotes recyclable materials; reverse logistics, which recycles and reuses products; and route planning optimization, which reduces fuel consumption and delivery time. Besides, the use of digital technologies such as Internet of Things (IoT) and Artificial Intelligence (AI) can enhance logistics efficiency and sustainability through real- time tracking, predictive capabilities, and automation.

Understanding Sustainable Logistics

Sustainable logistics, also known as green logistics, is defined as "supply chain management practices and strategies that reduce the ecological and energy footprints of the distribution of goods which focuses on material handling, waste management, packaging and transport".

1. Key Principles of Sustainable Logistics

The major principles of sustainable logistics are:

a. **Eco friendly Transportations**. Using fuel efficient vehicles, electric vehicles, or alternative fuels in order to reduce emissions.

b. **Route Optimization**. Using technologies to reduce fuel consumption and emissions by optimizing routes.

c. **Energy Efficiency**. Implementing energy-saving activities in transportation, warehousing, and distribution centers.

d. **Reduce Waste**. Encourage the use of biodegradable products, reduce packaging waste, and implement recycling.

e. **Transparency and Collaboration**. Including customers, suppliers, and stakeholders in ethical sourcing and sustainable practices.

2. Sustainability and Supply Chain Management

Sustainability has been a key component of modern supply chain management (SCM). Companies now know that sustainable logistics will enhance efficiency in operations, reduce risks, and promote their company reputation. Properly managed supply chain ensures:

a. **Optimization of resources**. Effective use of raw materials, reducing waste and energy consumption.

b. **Risk Mitigation**. Decreasing the dependency on non-renewable sources and compliance with environmental policies.

c. **Customer and Stakeholder Trust**. Meeting growing customer demands for ecologically sustainable products and services.

3. Triple Bottom Line: Economic, Environmental, and Social Aspects

Sustainable logistics is guided by the triple bottom line (TBL), balancing three elements:

a. **Economic Sustainability**. Being profitable by implementing cost-saving logistics techniques, such as fuel efficiency, waste minimization, and optimizing transportation. Capital investment in sustainability by companies generates long-term profits in terms of cost reduction and customer loyalty.

b. **Environmental Sustainability**. Reducing the footprint on the environment by restricting greenhouse emissions, decreasing energy consumption, and implementing ecologically friendly packaging. Techniques such as green warehouses, the use of renewable energy, and offsetting carbon footprint are the core strategies.

c. **Social Sustainability**. Addressing ethical sourcing, fair labor, and corporate social responsibility. Ensuring protection for employees, giving them fair pay, and engaging in community development programs contribute to a company's social responsibility.

4. Regulatory and Corporate Social Responsibility (CSR) Considerations

Governments and international organizations issue policies to encourage sustainable logistics. Some of the critical policies are:

a. **Emission Requirements**. Legislation such as the EU Green Deal and Paris Agreement promote low carbon emissions for logistics and transport.

b. **Waste Regulation Acts**. Regulations to manage wastage of packaging and recycle have an impact on businesses' compliance with sustainability.

c. **Environmental Procurement Guidelines**. Governmental institutions, corporations, and business organizations embrace suppliers who provide environmental sustainability credentials.

Key Environmental Challenges in Logistics

Sustainable logistics focuses on minimizing environmental impact while maintaining efficiency in the supply chain. Numerous environmental problems in logistics, such as carbon emissions from transportation, excessive energy consumption, enormous wastage production, and ineffective supply chains, hinder sustainable development (P. Karunarathna, 2024).

1. Carbon Emissions from Transportation

Transportation is a major contributor to greenhouse gas emissions due to its dependence on fossil fuels. Companies are exploring alternative fuels, electric vehicles, and route optimization methods to reduce emissions.

2. Energy Consumption in Warehouse and Distribution Centers

Warehouse and distribution centers require significant energy, and traditional warehouses use non- renewable energy sources. Efficient technologies like LED lighting, automation, and renewable energy sources can save energy.

3. Generation of Waste and Packaging Materials

The logistics industry generates waste from excessive packaging materials, which contributes to environmental pollution. Eco-friendly packaging methods and returnable packaging systems can minimize waste.

4. Supply Chain Inefficiencies That Lead to Environmental Degradation

Supply chain inefficiencies, such as inventory handling and overproduction, can lead to environmental degradation. Digital technologies like AI, blockchain, and IoT can enhance efficiency and reduce environmental impacts.

Sustainable Logistics Strategies

Sustainable logistics practice integrates the consideration of environment in supply chain management, emphasizing reduction of carbon emissions, minimization of waste, and increased efficiency in use of resources (Chamari Pamoshika Jayarathna, 2022). Some significant sustainable logistics practices, which companies can adopt, are mentioned below:

1. Green Transportation

Transportation involves the maximum amount of greenhouse gas emissions in supply chains. Green transportation practice lessens the footprint on the environment as well as stimulates efficiency of operations.

a. **Electric and Hybrid Vehicle Usage**. Moving towards electric (EVs) and hybrid vehicles reduce the usage of fossil fuels and lowers pollutants. Many logistics firms are spending money on hybrid vehicles for long-distance transport and EV fleets for last-mile deliveries.

b. **Efficiency of Fuel Route Optimization**. By choosing the shortest, least crowded routes, optimized route software reduces fuel usage. It reduces delivery time and cost in addition to emissions.

c. **Adoption of Alternative Fuels**. Carbon emissions can be greatly reduced by using hydrogen, liquefied natural gas (LNG), and biofuels as fuels. Compared to traditional diesel and gasoline, they provide a cleaner option.

2. Eco-Friendly Warehousing

Warehouses and distribution centers consume a lot of energy. Greening up with solutions can help make logistics more sustainable.

a. **Energy-Efficient Lighting and HVAC Systems**. Energy-efficient HVAC systems and LED lighting save energy and operating costs.

b. **Integration of Renewable Energy**. Warehouses can install solar panels and wind turbines to generate renewable energy, reducing their reliance on non-renewable energy sources.

c. **Green Building Certifications**. Getting certified by organizations like BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) guarantees that warehouses meet environmental performance standards.

3. Sustainable Packaging

Packaging is a major reliance of logistics, and sustainable practices can contribute significantly towards reducing waste and environmental harm.

a. **Use of Recyclable and Biodegradable Materials**. Recycling and using biodegradable packaging materials instead of plastic packaging lowers environmental pollution and trash going to landfills.

b. **Minimalist Packaging for Less Waste**. By implementing lightweight, smaller packaging, overall emissions are reduced because lower material is used and more space is available for transportation.

c. **Reusing Packaging with Reverse Logistics**. It is more economical and environmentally friendly to design reverse logistics practices to recycle packaging materials, such as pallets and returnable containers.

4. Reverse Logistics and Circular Economy

Reverse logistics is focused on returning products, recycling materials, and extending product lives, moving toward a circular economy.

a. **Product Refurbishing and Resale**. Organizations can reduce waste and make the most use of resources by refurbishing and reselling returned goods rather than dispose them away.

b. **Supply Chain Recycling and Waste Management**. Appropriate recycling initiatives guarantee that electronics, metals, and plastics are appropriately processed, recycled, and used for remanufacturing.

c. **Extended Producer Responsibility (EPR)**. Under EPR regulations, producers are held accountable for the full life cycle of their products, including recycling and disposal activities after consumption.

5. Technology and Innovation for Sustainable Logistics

Emerging technologies play a critical role in optimizing logistics activities and minimizing environmental effects.

a. Digital Twins to Effective Supply Chain Operations. Digital twins technology makes it possible for virtual replicas of logistic networks to exist, and these can be utilized by organizations to model and optimize operations for sustainability.

b. IoT, AI, and Blockchain Role. IoT enables real-time tracking of energy usage and emissions, and AI renders logistics planning more efficient. Blockchain technology enhances supply chain efficiency and transparency.

c. Electric and Self-Driving Delivery Solutions. Electric vehicles and drones reduce fuel consumption and emissions, enabling last-mile logistics to get greener.

Benefits and Drawbacks of Sustainable Logistics

1. Benefits

Sustainable logistic operations have multiple benefits which allow organizations to be efficient, reduce expenditures, and even enhance reputation (Mariam Lazrak, 2023). Some of the key benefits are:

a. Cost Reduction. Because of energy-saving vehicles, optimal routes, and minimizing waste, companies can save their operating expenses. For example, using energy-saving vehicles or consolidating shipments together saves energy, and therefore long-term savings are realized.

b. Environmental Impact Minimization. Green logistics minimizes the environmental impact, greenhouse gas emissions, air pollution, and environmental degradation as a whole. With environmentally friendly transportation and waste reduction, organizations contribute to environmental conservation and climate protection.

c. Compliance with Regulations. Governments of all countries are now implementing regulations that will assist in lessening environmental footprints. The use of green logistics assists companies in complying with the regulations, hence evading any potential fines or penalties.

d. **Brand Image and Reputation**. Consumers are becoming greener in their attitudes and like to deal with companies that practice corporate social responsibility (CSR). Green logistics policies can improve the reputation of a company, build customer confidence, and acquire green customers, ultimately contributing to the company by expanding market share.

e. **Operational Efficiency**. Green logistics often the use of technology and systems to improve efficiency in the supply chain. This includes improved inventory control, routing optimization, and minimization of waste. Such improvements lead to improved delivery times and efficient use of resources.

2. Challenges

Despite the multiple benefits, implementing green logistics practices also has some negative aspects that have to be addressed by organizations:

a. **Initial Costs**. Green practices and green technologies can cost a tremendous amount of money initially. For instance, going electric or switching to renewable sources of energy can cost a lot at the initial phase, and not all companies can afford to make the investment.

b. **Supply Chain Sophistication**. It may not be possible to make the highly complex global supply chain more sustainable. It will be hard to find alternatives or similar players interested in sustainability, and therefore, it may prove to be a challenge to become more sustainable at the whole supply chain level.

c. **Technological Integration**. Integrating new technology into the pursuit of sustainability, like real-time monitoring devices, green energy sources, or power-saving equipment, can be difficult and require radical changes to current infrastructure.

d. **Regulatory Uncertainty**. As environmental laws constantly change with dynamics, businesses may struggle to align compliance with dynamic laws. They have to adapt to numerous different regulations within numerous spaces, which raises complexity and potentially leads to uncertainty in supply chain operations.

Future Trends In Sustainable Logistics

With the world more in need of sustainable means, the logistics industry is also being given a new perspective. The future of sustainable logistics will have it reducing carbon emissions, increasing efficiency, and changing with emerging technologies. These are some of the significant trends that will shape the future (José Antonio, 2020):

1. Electrification of Transportation

One of the most thrilling innovations is the move towards electric vehicles (EVs) in logistics. With battery technology advancing, electric vehicles and even drones are viable alternatives to traditional fossil fuel-burning transports.

2. Robotics and Automation

Automation will transform logistics by streamlining processes and reducing human error. Warehouse operations are becoming more automated through robotics, AI driven systems, and automated guided vehicles (AGVs) to reduce energy consumption and automate handling of inventory.

3. Eco-Friendly Packaging

There is further that is implementing sustainable packaging options, as businesses are now employing biodegradable, recyclable, and reusable packaging materials. Lighter and cleaner packaging technology developments can readily offset the generation of waste and the overall contribution of the logistics industry to the environment.

4. Circular Supply Chain Models

A circular economy approach based on recycling, reuse, and minimizing waste is becoming prevalent in logistics. It is emphasizing the development of a closed-loop system where material is recycled again and again and waste is kept to a minimum.

5. Data-Driven Sustainability

Use of big data and AI allows companies to make informed decisions about their logistics operations. Predictive analytics guarantees the best route planning, conserving fuel and emission. Real-time tracking and optimization platforms assist companies in computing their carbon footprint and making greener practices.

6. Sustainable Last-Mile Delivery

The last-mile delivery division, responsible for the final leg of the journey to the customer, is a key area for sustainability efforts. Companies are exploring solutions ranging from electric bicycles to drones and neighborhood delivery hubs to reduce emissions and urban congestion.

Recommendations

1. **Adopt Green Transportation Practice**

a. Encourage the use of green or electric vehicles for logistics activities.

b. Use AI and data analytics to plan routes for deliveries in a way that will consume less fuel.

c. Collaborate with third-party logistics providers whose business model is based on sustainability.

2. **Invest in Green Warehouses**

a. Install energy-efficient lighting and cooling systems to reduce energy consumption.

b. Use sustainable building materials and design the warehouses to allow efficient natural light and air circulation.

c. Reduce waste through recycling programs and electronic inventory management to avoid paperwork requirements.

3. **Leverage Technology for Sustainable Operations**

a. Utilize Internet of Things (IoT) sensors to enhance fuel efficiency monitoring and optimization.

b. Utilize blockchain for transparent supply chain tracking to reduce wastage and inefficiencies.

c. Utilize automation to enhance accuracy in inventory management, reducing over production and waste.

4. **Encourage Sustainable Procurement and Supplier Collaboration**

a. Partner with eco-friendly suppliers.

b. Adopt circular economy strategies through concentration on product recycling and reuse.

c. Create sustainable packaging solutions to prevent material wastage.

5. **Enhance Employee and Stakeholder Participation**

a. Organize training sessions to educate employees on sustainable logistics practices.

b. Reward customer participation in green practices, such as green delivery.

c. Create clear-cut sustainability targets and periodically report them to stakeholders.

These practices help businesses integrate green components into their logistics functions as well as enhance efficiency and profitability. Green logistics is not an option but a necessity for businesses interested in prospering in the long run in the dynamic world they are moving toward.

Conclusion

Logistics is central to making it eco-friendly while maintaining efficiency in supply chain operations. In this article, it has been highlighted the way sustainable activities must be made a part of logistics with the focus on carbon footprint reduction, transport optimization, and green warehousing practices. It has also discussed challenges such as high cost of implementation, resistance to change, and the need for up gradation in terms of technology.

The discussion emphasized that firms must perceive sustainability as a long-term investment instead of a cost of regulation, which can increase brand reputation, customer loyalty, and overall business efficiency. Governments and regulatory bodies are also actively playing their part in encouraging sustainable logistics by framing policies, incentives, and guidelines that encourage businesses to green themselves.

Continuous improvement is essential in sustainable logistics because the environmental concerns as well as business conditions are likely to evolve over time. Companies must stay one step ahead in adopting new technology, optimizing supply chain processes, and creating a culture of sustainability in their operations.

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GREEN LOGISTICS: REDUCING CARBON FOOTPRINTS IN SUPPLY CHAIN OPERATIONS

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Abstract

Green Logistics plays a pivotal role in reducing the environmental effects of supply chain operations, primarily through carbon emissions from transportation, Warehousing, and Distribution. This study examines the feasibility of green logistics strategies such as green transport, energy-efficient warehousing, and circular supply chain. Based on qualitative case study data, the research examines how companies adopt green logistics strategies and how government policies promote enabling eco- friendly practices. It concludes that green logistics enhances sustainability and maximizes cost-benefits via route optimization, alternative fuel technology, and digitalization. Despite its benefits, large-scale implementation faces challenges, including high initial investment costs and inadequate infrastructure. This study demonstrates that policymakers and business leaders must collaborate to integrate green logistics into international supply chains. Prioritizing green logistics enables companies to achieve long-term economic and environmental benefits while remaining competitive in an increasingly environmentally conscious market.

Keywords: Green logistics, sustainable supply chain, carbon footprint, eco-friendly, transportation

Introduction

The world's largest carbon emitter, logistics is responsible for most of the damage to the environment by causing harm through transport, packaging, and storing, with the sector accounting for 14% of the world's greenhouse gas (GHG) emissions (International Energy Agency, 2023). With businesses wanting to cut down on climate change but not increase the cost exponentially, green logistics is a key strategy today, and it perfectly fits the conference theme of "Leveraging Adaptive Logistics in Building Resilient Supply Chains in a Volatile Global Economy" by emphasizing that sustainable practices make supply chains more resilient, dynamic, and sustainable in the long run. This study seeks to determine key green logistics practices to reduce carbon prints, quantify the advantages and challenges of adopting green logistics, and analyze the effect of government incentives and policies in promoting the shift towards green logistics.

Methodology

It employs the qualitative research approach, using:

1. Literature Review

Green logistics is a sustainable supply chain concept designed to minimize environmental impacts using low-carbon transportation, energy-efficient warehousing, and digital traceability systems. It integrates alternative fuel technologies, AI-driven logistics, and low-emission but highly efficient circular economy practices (Saberi, 2019). Studies suggest that green logistics significantly contributes to climate change mitigation while strengthening more supply chain resilience to market volatility (Sharma, 2024).

Several leading companies have succeeded in applying green logistics strategies. Amazon and DHL have adopted electric delivery vehicles and AI-driven route optimization to make delivery optimal and reduce carbon footprints. Maersk, a leader in global shipping has invested in the use of biofuels and blockchain-aided supply chain transparency (Wang, et al., 2020). AI- powered logistics systems also optimize the logistics with real-time monitoring and predictive data analysis, eliminating wasteful use of fuel and emissions (Leogrande, 2024). Blockchain technology enables supply chain sustainability with improved transparency and minimal inefficiency and ensures compliance with green logistics regulations (Saberi, 2019).

Despite all these developments, there are constraints on green logistics. Aside from the reality that electric cars are expensive to purchase upfront, AI-powered supply chain logistics and renewable energy have already created financial constraints for most organizations (Christopher, 2016). In addition, different laws across countries present further challenges to compliance and enforcement on standardized green logistics practices (Pratiwi, 2025). Resistance to technological change and concerns over return on investment (ROI) further slowdown adoption, particularly among small and medium-sized enterprises (SMEs).

Looking ahead, Future studies indicate that hydrogen-based transportation, combined with government policies aligned with the directive of sustainability, will have significant effects to the extent of propelling the adoption of green logistics (Zhang et al., 2023). The growth of green finance and carbon credit incentives is expected to drive investments in low-emission logistics technologies (Hossain, 2024). While businesses continue to navigate with ever more volatile global economic conditions, adopting green logistics is a necessity to respond to environmental sustainability and operational effectiveness.

2. Case Study Analysis

The article examines Amazon, DHL, and Maersk's green logistics usage in reducing carbon footprints. Amazon invests in electric trucks for delivery as well as biodegradable packaging, and DHL's GoGreen consists of alternative fuel vehicles as well as artificial intelligence-driven logistics optimization with a vision of providing zero-emission logistics by 2050. Maersk, being a shipping line, invests in biofuel and hydrogen fuel ships to enable green sea transport.

Green Logistics Strategies for Reducing Carbon Footprints

1. Green Transportation Solutions

Green mobility focuses on emissions reduction through alternative fuels and smart logistics. Electric vehicles (EVs) become mainstream with Amazon (its 100,000 EV fleet by 2030) and DHL (its 60% e- vehicles by 2030). Hydrogen fuel cell technology is on the horizon for trucks as well, with zero emissions and longer ranges. AI-routed optimization saves up to 20% of fuel by avoiding traffic congestion and optimizing shortest paths. In addition, intermodal transport (combining road and rail usage) cuts emissions through switching freight to lower-carbon transport modes.

2. Green warehousing and distribution

Green warehousing uses electricity-saving technologies like solar panels, motion detectors for LED lighting, and computer-programmed heating, ventilation and air conditioning (HVAC) systems to conserve electricity usage. Artificial intelligence (AI) computerized warehouse management systems (WMS) maximize storage configurations, avoiding unnecessary forklift movement and energy use. Some businesses use automated guided vehicles (AGVs) and robot picking technology to reduce energy-intensive manual labor. Cold storage warehouses are adopting thermal insulation and phase- change materials as methods of restricting refrigeration emissions.

3. Digitalization and IoT in Green Logistics

IoT fleet real-time tracking tracks fuel efficiency, idling, and optimal speed, reducing emissions by 10-15%. Blockchain provides green sourcing openness through tracking the carbon emissions of suppliers. Predictive analytics optimizes the route for minimum empty mileage. Circular economy uses reusable packages (e.g., Ikea drop-off boxes) and reverse supply chains (back-haul product refurbished or remanufactured, not wasted). Logistics 3D printing reduces transportation needs through localized production.

Benefits of Green Logistics in a Volatile Global Economy

Green logistics provides numerous advantages, particularly in an uncertain economic environment. The biggest benefit is cost saving, where reduced fuel and energy usage translates into lower operating expenses. Businesses that opt for sustainable logistics enjoy the advantage of being law-abiding, with no risk of potential fines for failure to conduct carbon reduction efforts. Also, an aggressive sustainability focus heightens brand image because consumers like green businesses. This cultivates customer loyalty and a greater brand image. Another key advantage is reduced risk because less use of fossil fuels protects companies from exposure to the threat of price and supply fluctuation, resulting in stability in the long term compared to unstable market trends.

Challenges in Implementing Green Logistics

Green logistics is also limited. The largest barrier is the colossal starting cost, as equipping electric vehicle fleets, AI logistics networks, and green infrastructures requires a considerable amount of capital. Furthermore, regulatory variance between nations is a challenge in adapting to them, which requires multinational corporations to implement a similar environmentally friendly practice. There are technological issues too because the application of IoT and AI technologies in the logistics process is a question of experience and investment. There is resistance to change, which is a major challenge because it is the unwillingness of most companies to adopt green practices due to fear of massive initial investment and uncertainty about whether they will get a return on investment or not. All these can be overcome only through the collective action of businesses, policymakers, and technologists to bring in sustainable change in global logistics.

Case Studies of Successful Green Logistics Implementation

DHL's Go Green program is a large-scale program to make its logistics zero-emission by 2050. One of the key components of this strategy is the introduction of the Go Green Plus service, which aims at the decarbonization of overland freight via carbon sequestration. The approach involves investment in green technologies and alternative fuels like electric vehicles, biogas (Bio-LNG or Bio-CNG), and hydrotreated vegetable oil (HVO) to cut down carbon emissions directly within DHL's transport chain. DHL Freight has already introduced several green road freight projects, including the deployment of electric and biofuel-powered trucks, which have resulted in a significant reduction in carbon emissions. DHL also employs data analytics to streamline routes, enhancing delivery efficiency and further lowering its carbon footprint. These initiatives supplement Deutsche Post DHL Group's overall sustainability goal of achieving net-zero logistics-related emissions by 2050.

A.P. Moller-Maersk, the world's biggest container shipping company, has committed to going net-zero for greenhouse gas emissions by 2040. One of the major components of this strategy is the integration of green methanol-fueled vessels, a less polluting fuel source than conventional marine fuels. Maersk unveiled the "Ane Mærsk," the world's largest methanol-fueled container vessel, in 2024, a huge leap towards green shipping. To support these ships, Maersk has struck long-term contracts to provide bio-methanol, including a major agreement with China's LONGi Green Energy Technology from 2026. Maersk is also studying the prospect of using green hydrogen as one of its substitute fuels, to diversify its energy provision and reduce emissions even more. To augment these efforts, the company has launched the Maersk ECO Delivery product that employs certified biodiesel from used cooking oil as fuel for ships, offering customers carbon-free shipping. These initiatives are an exemplification of Maersk's resolve to be at the forefront of innovation in sustainable trends in global shipping and pushing the industry towards greener logistics.

Company	Initiative	Metric	Source
Amazon	Electric delivery vans(20,000)	18% reduction in emissions per vehicle	Amazon Sustainability(2024)
	Recyclable packaging	11,000 metric tons of plastic waste eliminated annually	The Verge (2024)
DHL	Bio-LNG trucks	90% CO_2 reduction per km	DHL Group (2024)
	AI route optimization	15% less fuel consumption in Europe	DHL Freight (2022)
Maersk	Green methanol ships	65% lower GHG emission per voyage	Maersk (2024)
	ECO Delivery biodiesel	1 million tons of CO_2 saved (2024)	Reuters (2024)

Table 1: Quantitative Impact of Green Logistics Initiatives
Source: Compiled from Amazon, DHL, and Maersk reports (2024)

Government Policies Promote Enabling Eco-Friendly Practices

Green logistics is promoted by governments through regulation, incentives, and infrastructure support to provoke green behavior. Carbon restrictions and emissions mandates are forcing industries to move to low-emission transportation, while subsidies and tax credits reduce the expense for industries that move to green technology. Green port investment and EV charging facilities also spur sustainability. Carbon credits and emission trading systems (ETS) enable firms to offset carbon footprints, and mandatory reporting law ensures security and compliance. In addition, public-private partnerships (PPPs) enable the organization of collaboration to implement renewable energy and circular economies. All these collaborative approaches build together an enabling business environment to implement sustainable logistics that is economically sound.

Future Trends in Green Logistics

The future of 'green logistics' is policy-driven innovation, technology-driven innovation, and new business models. The most viable innovation is the innovation of hydrogen-based transport, with investors investing money in hydrogen fuel cells to power trucks and ships. The technology offers a cleaner method of carrying goods than traditional fossil fuels, and it decreases the emission rate of the supply chain even further. Another of the other dominant trend is the growth in the application of AI and IoT in delivering sustainable logistics. Supply chain companies can effectively manage their carbon footprint with AI-powered analytics, and hence, make informed decisions in warehouses and transport. IoT solutions enable real-time optimization of fuel efficiency and wastage. The world governments are also playing catch-up, with the stringent regulations on tighter levels of carbon emissions and individuals being encouraged to utilize carbon credits as an incentive for going green. With tightening regulations, firms must adapt to these added terms so that they are well-placed to cope with a green market. Finally, the circular economy model is also on the rise, with companies giving more emphasis to biodegradable and recyclable packaging. Not only do they reduce environmental pressures, but they also respond to consumers' demands for sustainability. Green logistics will be at the top of the mind in the future of supply chain management.

Conclusion

Green logistics is not just a green approach anymore, but supply chain resiliency in today's rapidly evolving global economy. By integrating sustainable transport, digital innovation, and the circular economy, businesses can minimize their carbon footprint without sacrificing efficiency and profitability. But with all its advantages of mass adoption, it is marred by constraints of limited resources, bureaucratic glitches, and the might of hi-tech. All these must be resolved by the initiative of business leaders, policymakers, and technology entrepreneurs for an ecosystem of green logistics to grow. And lastly, green logistics is not a fad but a strategic imperative for firms who wish to balance economic development with ecological sustainability. Firms that invest in sustainability will now be better prepared to withstand future supply chain dislocation and to compete in a more sustainable economy.

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GREEN PURCHASING, ECO DESIGN, REVERSE LOGISTICS AND GREEN TRANSPORTATION INCORPORATING ENVIRONMENTAL RESPONSIBILITY INTO SUPPLY CHAINS

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Abstract

Logistics sustainability is increasingly a top priority for businesses attempting to reduce the environmental impact without sacrificing performance. This study investigates four key sustainable logistics practices: Green Purchasing (GP), Eco-Design (ED), Reverse Logistics (RL), and Green Transportation (GT). Green Purchasing involves purchasing environmentally friendly inputs and suppliers with the goal of lowering ecological prints. Eco-Design integrates sustainable values into product design, making products recyclable and less wasteful. Reverse Logistics facilitates the return, reuse, and recycling of products, and it aids in a circular economy. Green Transportation emphasizes low-carbon and energy-efficient transportation means to minimize carbon footprints. Drawing on an in-depth analysis of these practices, this research determines their strengths, weaknesses, and strategies for implementation. (rivastava, 2007) The findings contribute to the growing body of research on sustainable supply chain management, and they offer insights for firms interested in economic and environmental sustainability.

Key words: Green purchasing, eco-design, reverse logistics, green transportation

Introduction

Sustainable logistics is the integration of environmental, social, and economic considerations into the design, planning, execution, and control of logistics operations and systems with the aim to minimize negative and maximize positive impacts. Sustainable logistics aims for a balance between economic growth, environmental sustainability, and social equity. Sustainability has emerged as a central topic in logistics and supply chain management in the recent past following the buildup of environmental issues and regulation requirements. Traditional logistics operations contribute to a significant percentage of carbon footprint, use of resources, and generation of waste and hence the implementation of more sustainable operations is inevitable. Sustainable logistics integrates environmental, social, and economic dimensions in supply chain activities to curtail negative ecological impacts without sacrificing efficiency and profitability.

Within numerous sustainability practices, four key practices Green Purchasing (GP), Eco-Design (ED), Reverse Logistics (RL), and Green Transportation (GT) stand out to make logistics an environmentally sustainable function. Green Purchasing focuses on procuring green materials and selecting suppliers with sustainability focus. Eco-Design focuses on integrating environmental concerns in product design, reducing waste, and enhancing recyclability. Reverse Logistics allows for the return, reuse, remanufacturing, and recycling of goods, fostering a circular economy. Green Transportation involves optimizing transport modes to minimize fuel consumption and emissions, in support of cleaner and more efficient logistics networks. Environmental responsibility in supply chains involves reducing carbon footprints, conserving natural resources, and adopting circular economy principles. Companies are increasingly integrating green practices into their logistics, with four practices in mind (Beamon, 2000).

While these sustainable practices have become more apparent, firms are faced with implementation challenges such as cost, lack of technological infrastructure, and resistance to change. This study aims to explore the applicability, benefit, and challenges of these four sustainability practices in logistics. Based on their influence and impact, this research provides valuable information on how companies can adopt and implement sustainable logistics initiatives to enhance environmental and economic performance.

Incorporating Environmental Responsibility into Supply Chains

As environmental problems continue to rise globally, the integration of environmental responsibility into supply chains has become a requirement for businesses that want to be sustainable. Sustainable logistics approaches seek to minimize environmental impact while still being efficient in the transportation of goods, services, and information. This approach not only mitigates environmental harm but also enhances corporate reputation, regulatory compliance, and profitability in the long term.

Green sourcing is one of the cornerstones of sustainable supply chain. Green Purchasing ensures raw materials, components, and services brought from suppliers who adhere with green guidelines. This controls pollution, wastage, and natural resource extraction and encourages eco-friendly production for industries. Green product design reduces environmental impacts throughout the product life cycle. Eco-Design combines recyclable materials, energy-efficient production processes, and reduced packaging waste. By incorporating sustainability into product development, businesses can minimize resource consumption and enable extended product lifetimes.

Reverse Logistics emphasizes backhauling, recycling, remanufacturing, and disposing of old products in a proper way. Reverse Logistics plays a central role in reducing landfill waste and maximizing material reuse. Reverse Logistics adheres to circular economy principles to make sure that supply chains are environmentally sustainable in the long term. Transport is a key source of carbon emissions in supply chains. Green Transportation measures, such as routing optimisation, the use of fuel-efficient or electric vehicles, and the leveraging of intermodal transport, reduce emissions and energy consumption. Such measures not only have environmental advantages but also boost cost-effectiveness.

Through the implementation of these green logistics practices, businesses can primarily improve their ecological footprint while not having to compromise competitiveness. Businesses that implement ecologically sound supply chains demonstrate their commitment to sustainability, adhere to regulatory requirements, and react to the growing demand for environmentally conscious products and services.

Key Principles of Sustainable Logistics Practices with Environmental Responsibility

To effectively integrate environmental responsibility into supply chains and logistics, organizations must adhere to several key principles. These principles guide businesses in reducing their ecological footprint while maintaining operational efficiency:

1. **Environmental Responsibility & Compliance**. Ensure compliance with environmental regulations and international sustainability standards such as ISO 14001, Paris Agreement, and ESG frameworks. Implementing corporate sustainability policies that align with legal and ethical environmental requirements.

2. **Green Purchasing (GP) & Sustainable Sourcing**. Prioritize eco-friendly suppliers who use sustainable materials and energy-efficient processes. Establish green procurement policies to minimize environmental impact in raw material acquisition. Encourage supplier collaboration to reduce waste, emissions, and resource consumption.

3. **Eco-Design (ED) & Circular Economy Principles**. Integrate sustainable materials and energy-efficient processes into product design. Focus on recyclability, durability, and reduced waste generation across the product lifecycle. Adopt a cradle-to-cradle approach, ensuring minimal environmental harm from production to disposal.

4. **Reverse Logistics (RL) & Waste Reduction**. Develop efficient systems for product returns, remanufacturing, and recycling. Implement take-back programs to ensure proper disposal or reuse of products. Minimize landfill contributions by repurposing end-of-life products and components.

5. **Green Transportation (GT) & Carbon Footprint Reduction**. Optimize transportation routes and use low-emission vehicles (e.g., electric or hybrid trucks).Promote the use of alternative fuels, such as biofuels and hydrogen-powered logistics fleets. Enhance freight consolidation and intermodal transportation to improve fuel efficiency.

6. **Energy Efficiency & Resource Optimization**. Implement smart logistics systems using IoT and AI for real-time tracking and energy optimization. Utilize renewable energy sources in warehouses, distribution centers, and fleet operations. Reduce excessive packaging and encourage reusable, biodegradable, or recycled materials.

7. **Stakeholder Collaboration & Corporate Social Responsibility (CSR)**.Engage stakeholders, including suppliers, customers, and governments, in sustainability efforts. Invest in employee training and awareness programs to foster a culture of environmental responsibility. Adopt transparent reporting and sustainability disclosures to track and communicate environmental performance.

8. **Economic Viability & Long-Term Sustainability**. Balance environmental goals with economic feasibility to ensure sustainable financial performance. Leverage green technologies and innovations that offer long-term cost savings and operational efficiencies. Monitor sustainability metrics and continuously improve logistics strategies to enhance long-term resilience.

Benefits of Sustainable Logistics Practices with Environmental Responsibility

Adopting sustainable logistics practices such as Green Purchasing (GP), Eco-Design (ED), Reverse Logistics (RL), and Green Transportation (GT) offers a wide range of benefits and can be categorize in to three main components environmental, economic, and social. These practices help organizations not only meet regulatory standards and public expectations but also enhance long-term resilience and competitiveness (Rogers, 2000).

Environmental Benefits

1. **Reduced Carbon Emissions**. Implementing green transportation methods (e.g., electric vehicles, route optimization) leads to a significant reduction in greenhouse gas (GHG) emissions. Energy-efficient warehouses and reverse logistics reduce fuel use and energy consumption.

2. **Lower Resource Consumption**. Green purchasing ensures that materials are sustainably sourced, reducing the extraction and depletion of natural resources. Eco-design promotes the use of renewable and recyclable materials, lowering the environmental burden.

3. **Waste Minimization**. Reverse logistics helps reduce landfill waste by enabling reuse, recycling, and proper disposal of products also Sustainable packaging and product designs result in fewer byproducts and pollutants.

Economic Benefits

1. **Cost Savings over Time**. Energy-efficient logistics and optimized transportation routes cut fuel and operational costs. Reverse logistics allows the recovery of valuable materials and products, lowering raw material costs.

2. **Improved Operational Efficiency**. Smart logistics systems, leaner supply chains, and waste reduction improve efficiency and reduce downtime. Green practices promote better inventory management and lifecycle planning.

3. **Increased Brand Value and Competitive Advantage**. Companies with strong sustainability profiles attract more eco-conscious customers and investors. Differentiation through green practices enhances corporate reputation and market appeal.

4. **Regulatory Incentives and Risk Mitigation**. Compliance with environmental standards avoids fines and legal risks. Many governments offer tax incentives, subsidies, or carbon credits for green initiatives.

Social and Ethical Benefits

1. **Improved Stakeholder Trust and Reputation**. Consumers, investors, and communities are more likely to support businesses committed to environmental stewardship. Sustainable practices demonstrate corporate social responsibility (CSR) and ethical operations.

2. **Employee Engagement and Satisfaction**. Employees are more motivated to work for organizations that prioritize sustainability and ethics. Training and involvement in green initiatives improve morale and loyalty.

3. **Support for Global Sustainability Goals**. These practices contribute to the UN Sustainable Development Goals (SDGs), such as SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action).Businesses become part of the global movement toward reducing climate change and promoting environmental justice.

Challenges in Adapting to Sustainable Logistics Practices

1. **High Initial Investment Costs**. Implementing sustainable practices often requires significant upfront capital investment, including: Purchasing energy-efficient vehicles or electric fleets. Installing renewable energy systems in warehouses and facilities. Upgrading IT systems to track and optimize sustainability metrics. Switching from diesel trucks to electric vehicles can be cost- prohibitive for small to medium enterprises (SMEs), despite long-term savings.

2. **Limited Supplier Availability and Compatibility**. Sustainable green purchasing is often hindered by a lack of reliable, eco-friendly suppliers. Not all suppliers

meet environmental standards, and switching suppliers may disrupt existing supply chain relationships. There may also be inconsistencies in certification or verification of green credentials. A manufacturer may find it difficult to source biodegradable packaging materials that meet both quality and sustainability standards.

3. **Complexity in Eco-Design Implementation**. Integrating eco-design principles into existing product lines requires major changes in design thinking, engineering, and production processes. Balancing functionality, aesthetics, cost, and sustainability can be difficult. Lack of technical expertise in eco-design practices is another key barrier. A company designing consumer electronics may struggle to create fully recyclable components without compromising on performance or durability.

4. **Operational Challenges in Reverse Logistics**. Reverse logistics systems require complex infrastructure for returns, sorting, remanufacturing, and recycling. There is often unpredictability in returned product quality, quantity, and timing. Reverse logistics can also be cost-intensive if not managed properly-commerce companies managing large volumes of product returns face high logistical costs and difficulties in refurbishing used items for resale.

5. **Lack of Technological Infrastructure**. Many organizations, especially in developing countries, lack advanced technology for tracking emissions, energy consumption, and sustainability metrics. Integrating IoT, AI, and big data analytics into logistics systems can be technically and financially demanding. Ex: Small logistics firms may not afford or understand the use of real-time carbon tracking systems or smart fleet management software.

6. **Regulatory Uncertainty and Compliance Pressure**. Environmental regulations vary across regions and are frequently updated, making compliance a moving target. Businesses operating across international borders face difficulty navigating multiple environmental laws, trade policies, and standards. Ex: A company exporting to the EU must comply with stringent packaging waste and carbon footprint regulations, which may not align with local practices.

7. **Resistance to Organizational Change**. Shifting toward sustainability often faces internal resistance due to organizational inertia, lack of awareness, or fear of increased workload. Employees and management may be reluctant to change established practices or invest time in new systems and training.Warehouse staff may resist changes to traditional logistics routines in favor of eco-friendly protocols that are initially unfamiliar or less convenient.

Future Trends in Sustainable Logistics Practices

1. **As global supply chains face increasing pressure to reduce their environmental impact**. Sustainable logistics is evolving rapidly, driven by technological innovation, regulatory frameworks, and stakeholder expectations. The future of logistics will prioritize efficiency, circularity, transparency, and climate resilience, transforming the way goods are moved and managed (McKinnon, 2010).

2. **Widespread Adoption of Electric and Alternative Fuel Vehicles**. Electric vehicles (EVs), hydrogen-powered trucks, and biofuel alternatives will increasingly replace traditional diesel fleets in logistics. Reduces dependency on fossil fuels Lowers greenhouse gas emissions. Aligns with national net-zero targets Ex: Amazon and FedEx are integrating electric delivery vans at scaled is investing in zero-emission last-mile fleets.

3. **Integration of Artificial Intelligence (AI) and Internet of Things (IoT)**. AI and IoT technologies will power predictive analytics, real-time tracking, and automated decision-making in green logistics systems. Enhances route and load optimization Reduces fuel usage and idle times. Enables real-time emissions monitoring. As examples Smart warehouses using AI to manage inventory and reduce waste, IoT devices tracking temperature and CO_2 levels in shipments.

4. **Rise of Circular Supply Chains**. Circular economy principles will be more fully embedded, emphasizing reuse, refurbishing, recycling, and reverse logistics. Minimizes landfill waste, Maximizes resource efficiency, Supports closed-loop product systems. Ex: Companies offering product take-back programs and Manufacturers designing for disassembly and recycling.

5. **Green Infrastructure and Carbon-Neutral Warehouses**. Logistics facilities will shift toward carbon-neutral operations through renewable energy, automation, and sustainable construction. Reduces operating costs and emissions Supports net-zero logistics networks, Improves building energy performance. Ex: Warehouses powered by solar panels and wind turbines Use of green roofing and passive cooling systems.

6. **Blockchain for Green Supply Chain Transparency**. Blockchain technology will provide secure, traceable records of products' environmental impact across the supply chain. Verifies green certifications, Enhances supplier accountability, Builds consumer trust through transparency Ex : Tracking carbon credits and ethical sourcing through blockchain and Blockchain-based emissions tracking for each shipment.

7. **Growing Focus on Sustainable Packaging**. There will be a push for biodegradable, reusable, or minimal packaging materials that align with environmental goals. Reduces plastic and packaging waste Lowers total shipping weight (and fuel use). Improves brand sustainability image . Ex Plant- based packaging innovations, Brands adopting "ship in own container" models.

Recommendations for Implementing Sustainable Logistics Practices with Environmental Responsibility

To effectively adopt and sustain environmentally responsible logistics practices, organizations must take a strategic, integrated approach that aligns sustainability goals with operational performance. Based on the analysis of Green Purchasing (GP), Eco-Design (ED), Reverse Logistics (RL), and Green Transportation (GT), the following recommendations are proposed (Zhu, 2004):

1. **Develop a holistic sustainability plan**. Firms ought to develop an open and tangible sustainability roadmap incorporating environmental goals into holistic logistics procedures. The plan must define short-term and long-term sustainability targets. Cascade environmental KPIs across the enterprise. Comply with global standards (e.g., ISO 14001, SDGs).

2. **Invest in Green Technologies and Infrastructure**. Make Investments in Green Technologies and Infrastructure While a high initial investment is made, green technology investment saves money in the long term and is more resilient. Companies need to Transition to electric or hybrid car fleets and install EV charging stations. Replace warehouse equipment and lighting with efficient equipment. Replace equipment with smart systems (IoT, AI) for real-time monitoring and emissions tracking.

3. **Enhance Supplier Cooperation and Green purchasing**. To facilitate Green Purchasing Conduct sustainability audits of suppliers. Collaborate with suppliers to develop more sustainable materials and processes. Incentivize compliance with green standards through long-term contracts or preferred status.

4. **Apply ECO design into product**. Sustainability has to be incorporated at the product design phase. Organizations have to: Train design teams on eco-design practices. Use life cycle assessment (LCA) tools to measure environmental impact. Encourage materials and packaging innovation to enable recyclability and reuse.

5. **Build Efficient and Scalable Reverse Logistics Systems**. To maximize value recovery and minimize waste: Establish product take-back, repair, and recycling programs. Invest in return centers with sorting and refurbishing capabilities. Use data analytics to forecast returns and improve planning accuracy.

6. **Enhance Transportation Efficiency and Carbon Management**. Green Transportation can be optimized by: Implementing route optimization software to reduce fuel usage. Shifting to intermodal transportation where feasible. Monitoring carbon emissions per shipment and setting reduction targets.

7. **Increase Organizational Awareness and Training**. Cultural change is essential for sustainability. Organizations should: Conduct regular training on green practices for employees at all levels. Create cross-functional sustainability teams to oversee initiatives. Reward sustainability- driven innovation and performance.

Conclusion

Sustainable logistics is today an essential part of modern supply chain management, answering the call to minimize environmental impact without compromising efficiency and profitability. The integration of Green Purchasing (GP), Eco-Design (ED), Reverse Logistics (RL), and Green Transportation (GT) demonstrates that logistics activities can be harmonized with environmental sustainability without undermining business performance.

With increasingly stringent environmental regulations and rising consumer pressure for ‘green’ products, businesses must adopt green practices proactively in order to remain competitive and give back to society. The environmental, economic, and social benefits of sustainable logistics such as reduced emissions, improved operational efficiency, and enhanced brand reputation highlight its contribution as a long-term driver of value.

However, with challenges such as exorbitantly high up-front expenditures, limited technological infrastructure, and opposition to change, strategic planning, investment, and collaboration along the supply chain are called for. Those companies that invest in innovation, stakeholder engagement, and continual improvement of their sustainability programs will not only reduce their environmental footprint but also build stable and future-proofed logistics chains. Lastly, a shift to sustainable logistics is not just a reaction to environmental concerns a reactive action but a proactive strategy that propels long-term growth, regulatory compliance, and global sustainability. The moment of truth is now for organizations, paving the way for a greener, smarter, and socially responsible supply chain landscape.

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DEVELOPING A GUIDELINE TO REGULATE THE SKIN WHITENING PRODUCTS IMPORTING PROCESS IN SRI LANKA

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Abstract

The use of skin whitening products that has been imported in Sri Lanka contains dangerous substances such as mercury, hydroquinone, and steroids having extremely negative side effects such as skin decay, destruction of kidneys and even cancers. There has been an increased demand for skin whitening products from women by social and cultural values and yet the Sri Lankan state does not have sufficient legislation governing the centers. This study provides basis that shall be used for the regulation of imports. This study hence confirmed that through a qualitative study involving 17 interviews with stakeholders, there are various problems in importation; namely HS code loop holes, sample approval fraud, and inadequate enforcement. The outcomes show that health risks associated with climate change are very high yet the awareness of the population of such threats is still very low. Measures that have been proposed are preliminary testing before importing products, improvement of controls at the borders, rigorous regulation of adverts, and campaigns for creating awareness to the customers. According to the recommendations, one is discouraged from registering a bioequivalent product before ensuring that it complies with WHO and European Union standards as far as safety is concerned. The following steps may reduce health threats, safeguard the customer, and ensure ethical advertising. It assists policymakers regarding imports since they are a determinant factor in the market.

Keywords: Skin whitening products, health risks, regulation and policy

Introduction

There is an ever-increasing market of skin whitening around the globe and this has been motivated by issues such as social networking and promotions (Doshi, 2018). In Sri Lanka specifically the females the fair skin is sought for social rank and more chances (Arachchige et al., 2020). Many of them are made of poisonous materials such as mercury which causes side effects on the skin, kidney diseases, cancer among them (Rathnayake, 2022). Sri Lankan dermatologist Dr Kahawita noting that use of such creams results in daily cases of skin problems, (Daily Mirror, 2024). Other reports such as the ones conducted by the Centre for Environmental Justice reveal that many products contain very high levels of mercury that are dangerous thus showing that there are gaps in the regulation of the use of such products (Biodiversity Research Institute, 2024).

Research Problem

Sri Lanka experiences severe health risks from uncontrolled skin whitening products because these substances create various forms of skin harm and extended negative effects (Pollock, 2020). Demand for skin whitening products rises because of cultural and social media influences while people stay uninformed about possible adverse effects (Yusuf et al., 2019). Sri Lanka operates without any legal framework that monitors cosmetics imports which results in difficulty in controlling imports (Biodiversity Research Institute, 2024). Protecting public health together with promoting natural beauty requires strict regulations and better awareness (Fonseka & Wijekoon, 2019).

Aim

To develop a guideline to regulate the whitening products importing process to Sri Lanka, while identifying the existing regulatory gaps associated with the importation of skin whitening products in Sri Lanka.

Objectives

1. To analyze the health impacts associated with the use of imported skin-whitening products.

2. To examine the regulatory gaps associated with the importation of skin-whitening products in Sri Lanka.

3. Develop a guideline to regulate the whitening products importing process to Sri Lanka.

Research Questions

1. What are the health impacts associated with the use of imported skin-whitening products?

2. What are the regulatory gaps associated with the importation of skin-whitening products in Sri Lanka?

3. How can a guideline be developed to effectively regulate the importation process of skin-whitening products in Sri Lanka?

Literature Review

Sri Lankan citizens experience multiple health problems when using unregulated skin whitening products because these products lead to skin atrophy and telangiectasia in addition to acne and trigger psychological effects of anxiety and depression (Pollock, 2020; Fonseka & Wijekoon, 2019). The community-wide demand for lighter skin tone that especially affects women leads to intensified psychological distress (Poisonous Beauty, 2023). Contrary to regulations these products include mercury and hydroquinone and steroids that create substantial health dangers that affect the kidneys and trigger skin cancer and brain disorders (World Health Organization, 2019). Medical research shows that some products contain excessive mercury amounts beyond permissible levels leading to permanent conditions such as organ damage and memory problems and tremors (Sri Lanka Journal of Medicine, 2020). Patients choose dangerous white skin creams because of colonial-defined beauty standards which simultaneously destroy their self-assurance and support continuing damage from these harmful substances (Madarasingha, 2022). Regulatory control of white creams and awareness programs about their risks require implementation to lower harmful ingredients while maintaining public safety standards (Fonseka & Wijekoon, 2019).

1. Regulatory Gaps in Sri Lanka

The unregulated imported skin whitening products sold in Sri Lanka produce health problems that mimic steroid-induced skin damage such as telangiectasia and skin atrophy and acne (Fonseka & Wijekoon, 2019). Border control risks escalate due to unregistered product smuggling through customs combined with insufficient product checks (Mawrata News, 2024). Sri Lanka operates without nationally standardized pre-import safety tests because its regulatory enforcement varies between locations and its penalties are too minimal. Very few people understand the situation while the marketing sector faces no restrictions. International safety benchmarks are incompatible with Sri Lanka's regulatory framework because of which the country fails to implement optimal safety practices (WHO, 2020).

2. Existing Regulatory Frameworks and Global Best Practices

Skin-whitening products require evaluation followed by approval from both the Sri Lanka Standards Institution and National Medicines Regulatory Authority. The approval process faces numerous difficulties due to process manipulation along with corruption and bribery and product usage loopholes and insufficient ingredients scrutiny. The oversight mechanisms show poor digital integration and weak support between entities together with weak enforcement activities.

3. Global Best Practices

The EU and United States enforce strict regulatory measures concerning skin-whitening imports by analyzing chemicals, conducting tests on the products, upholding GMP requirements, requiring centralized tracking systems and advertising regulation standards with certified importer programs and real-time tracking protocols alongside nondiscrimination penalties for non-compliance as well as consumer education initiatives and multinational prevention efforts to exclude harmful merchandise from distribution.
Key Recommendations for Sri Lanka Based on Global Best Practices.

A new policy would enforce pre-import tests for cosmetics and require NMRA certification together with strengthened regulatory oversight, enhanced GMP standards and advertising rules, heightened consumer knowledge, more severe non-compliance penalties and international prevention programs against market entry of unsafe cosmetics. The policy requires customs and regulatory bodies and health organizations to work together.

Research Methodology

The research conducted qualitative work to create regulatory standards for skin-whitening product imports in Sri Lanka. The research investigated both current regulatory structures and the enforcement challenges together with healthcare dangers from whitening products. The study collected data from specialists in policy development, product management, medical services and international business to both understand fundamental problems and design tailored recommendations and insights.

1. Data Collection Methods

Semi-structured interviews served as the primary data collection method because they enable researchers to obtain extensive first-hand knowledge from essential sources within qualitative research. Semi-structured interviews served well because they achieved an optimal blend between the control of standardized questions and participant freedom to discuss new topics.

2. Interview Process

A total of 17 expert interviews were conducted with professionals directly or indirectly involved in the importation, regulation, and public health management of skin-whitening products.

Category	Code	No. of Respondents	Designations
Supply Chain & Customs Professionals	SCC	04 (SCC_1 to SCC_4)	Senior Supply Chain Executives, Executives, Customs Officers, Import Coordinators,
Healthcare Professionals	HCP	10 (HCP_1 to HCP_10)	Dermatologists, Nursing Officers, Dermatologists, Cosmetologists, Medical Consultants
Import-Export Banking Manager	IEB	01 (IEB_1)	Banking Manager - Trade & Import Operations
Legal Professionals	LP	01 (LP_1)	Attorney at Law
Media Professionals	MP	01 (MP_1)	Media Director

Table 1: Respondent's Profile
Source: Author

3. Data Saturation

The 17^{th} interview marked the point where data saturation occurred thus confirming previously gathered data without bringing new themes or perspectives to the study. Research methods along with resource efficiency remained strict because no additional interviews were done.

4. Sample Selection and Sampling Technique

The research method employed snowball sampling to acquire specialized participant groups who were difficult to reach such as industry professionals alongside regulatory bodies. The approach successfully attracted well-informed participants from all the essential stakeholder communities who manage skin-whitening product importation and supervision.

5. Composition of the Sample

The researchers brought together different experts from regulatory authorities, healthcare professionals, importers and distributors, legal professionals, customs officials and media professionals to obtain multiple perspectives about unregulated skin-whitening products' health issues and their effects on public health and product imports.

6. Justification for Sample Size

Whereby 17 interviews were conducted and the number considered sufficient since data saturation was reached after the 17 interviewees recruited. The goal was to conduct 10–15 interviews at first, but subsequently more interviews were conducted to make sure all relevant views were gained. The number of interviews conducted was 17; no new themes were identified in the 17th interview; hence, no more interviews were necessary.

7. Data Analysis

The researchers employed thematic analysis to evaluate the interview data which produced repeated findings regarding regulations and health risks alongside proposed policy solutions. The research method allowed stakeholders to gain both systematic knowledge and deeper understanding of their specific concerns.

8. Ethical Considerations

The research followed ethical procedures by getting permission from participants while using secure data management practices in addition to maintaining strict confidentiality.

Data Analysis and Findings

1. Weaknesses in the Current Importation Process

The SCC_3 report brings attention to specific issues regarding manipulated sample approvals as well as improper personal-use exemptions and problematic Harmonized System (HS) code identification. Inspected alternative samples instead of actual goods violate consumer safety because importers deceive the safety checks. When the personal-use exemption gets misused it produces illegal market sales of products which frequently result in safety issues. Failure of the Harmonized System code to perform detailed chemical analysis creates an entry opportunity for toxic products to reach Sri Lanka without proper inspection. Importers obtain their raw materials from nations that lack required documentation and regulatory permissions to bypass safety requirements.

Recommendations for import verification and enforcement measures:

a. Introduce the verification procedures for product samples to make them compulsory.

b. Specific measures should be taken regarding; enforcement of personal-use import quantities.

c. Introduce new codes regarding chemical composition of the products to the HS.

d. Review the process of the approval of their regulation.

e. Increase frequency of surveillance and ‘stop and search’ at the ports.

f. Suggest raising the penalties that are provided for in the legislation for such failures as misdeclaration or providing misleading information.

g. Additional documentations for large quantity of raw materials that would be imported.

2. Health Risks of Unregulated Whitening Products

Uncontrolled whitening products cause substantial health problems through their contained toxic materials including mercury, hydroquinone and corticosteroids. The lack of ingredient disclosures from importers gives customs officers and regulatory bodies limited access to perform safety evaluations on imported goods. The medical field observes patients experience worsening skin quality as well as reactions that produce allergies and pigmentation problems. The restricted testing facilities available in Sri Lanka hinder the ability to check imported whitening products in labs. Ill-designed regulations enable harmful low-quality products to reach the market which proves why strong product regulations must be established.

Recommendations for importation of whitening products in Sri Lanka:

a. Mandatory chemical composition testing before product approval.

b. Nationwide awareness campaigns to educate consumers about toxic whitening ingredients.

c. Aligning Sri Lanka's import policies with international health standards.

d. Introduction of pre-market clinical trials for long-term effects assessment.

e. Stringent labeling requirements for imported cosmetics.

f. Strengthening laboratory testing infrastructure for whitening product screenings.

3. Regulatory Gaps and Lack of Enforcement

The import regulation in Sri Lanka lacks effective enforcement because agents do not collaborate properly between customs and health regulators and consumer protection agencies and because there is no centralized system to track imports. The inefficiency of the process stems from three main factors including paper-based documentation, bureaucratic inefficiencies alongside the absence of standardized certification processes.

Recommendations for improving cosmetics inspection in Sri Lanka:

a. Implementing a digital tracking system for improved monitoring and accountability.

b. Training programs for customs officers to identify and intercept unsafe cosmetic imports.

c. Allocating more resources to regulatory bodies to enhance enforcement capabilities.

d. Random market inspections and periodic audits to remove unsafe whitening products.

e. Implementing electronic tracking of imports to monitor supply chain.

f. Establishing a standardized certification system for imported cosmetics.

4. Loopholes in advertising imported skin whitening products

The MP_1 showed that product import laws and advertising regulations have separate standards when it comes to the advertising and import of skin-whitening products. The Sri Lankan market allows advertising of whitening products which global authorities have banned despite their advertising approval. Products can obtain social media promotional slots because there exist gaps between legal guidelines. The current problem in the industry involves shortcomings in import regulation and dangerous chemical use and inadequate digital watch processes. The government should establish synchronized policies which prohibit advertising of banned products along with robust bulk import oversight and enhanced social media control and improved product labeling and consumer instruction.

5. Influence on using imported skin whitening products

LP_1 advocates that Sri Lanka should adopt stricter regulations for skin-whitening products because there are insufficient legal measures and public pressure against such cosmetics. The authors advocate for both a specification limit as well as testing standards and increased legal action constraints in the regulations. Changing negative social perceptions about skin color will help decrease the market demand for these risky products. Producers remain vulnerable because there is a deficiency in the system which should classify products according to ingredient safety thresholds.

Justification: Research Objectives Coverage

1. Objective 1

To analyze the health impacts associated with the use of imported skin-whitening products. The excessive use of imported skin-whitening substances by Sri Lankan consumers produces multiple health problems which include skin atrophy and acne and kidney damage along with elevated cancer dangers. The majority of these products introduce toxic substances which include mercury and hydroquinone and steroids.

Consumer markets lack a proper mechanism to block dangerously harmful products according to WHO and the Centre for Environmental Justice. Scientific and medical research in this study extensively examines the health effects of whitening products.

2. Objective 2

To examine the regulatory gaps associated with the importation of skin-whitening products in Sri Lanka.

The study demonstrates that Sri Lanka faces regulatory challenges in skin-whitening product importation by showing how regulatory approvals get manipulated and how products get misidentified through HS codes and inspections fail to meet regulatory standards. The experts establish that importers exploit these regulatory gaps to bring unregulated goods into the country. Sri Lanka operates without digital tracking systems and has insufficient customs training while facing weak punishment system for non-compliance regulations. The study details all weaknesses in product importation by showing that illegal skin whitening products enter through uncontrolled distribution channels.

3. Objective 3

Develop a guideline to regulate the whitening products importing process to Sri Lanka. The research work outlines a plan to establish proper oversight for skin-whitening import trade in Sri Lanka. The plan for better import regulation in Sri Lanka requires strict product monitoring alongside stronger inspection systems and greater advertising oversight and worldwide compatibility of local standards. Together with public health education the report identifies Good Manufacturing Practices (GMP) as necessary. Collected data enables policymakers alongside regulatory agencies and public health organizations to create stronger importation regulations which will better protect consumers. This research establishes successful combinations between medical data and regulatory assessments and policy advice.

Conclusion

Guideline to regulate the whitening products importing process in Sri Lanka:

1. Pre-Import Approval Requirements

National Medicines Regulatory Authority (NMRA) necessitates skin whitening product imports that include complete ingredient listings and international Certification of Analysis and GMP certifications. A NMRA-registered importer holds the exclusive right to bring skin whitening products into Sri Lanka while all hazardous substances remain illegal for importation.

2. Customs and Border Control Measures

Sri Lanka aims to strengthen white cream inspections by modernizing HS codes and establishing random testings and testing labs and surveillance activities to block forbidden imports that could be incorrectly classified as safe products.

3. Stronger Regulatory Oversight and Market Surveillance

Establishment of a tracking database for whitening products imports should be complemented by market inspections and electronic tracking systems while banning dangerous home-made productions.

4. Tightening Advertisement and Marketing Regulations

The regulation outlaws' deceptive promotions and demands proof back ended by science before allowing whitening product claims and sets harsh penalties for social media and marketing entities that market dangerous products.

5. Consumer Awareness and Public Health Initiatives

A nationwide educational program for 9consumers about unsafe whitening products and doctors should advise consumers about safe skincare and people must have a hotline to report both harmful reactions and unregulated products.

6. Stronger Enforcement and Legal Penalties

The government should increase penalties against importers who violate regulations while creating a special enforcement unit to inspect products and ordering Importer product returns when post-market surveillance tests fail.

7. Alignment with International Standards

Sri Lanka needs to implement worldwide cosmetic import rules and work with international agencies for product assessment alongside needing importers to prove international safety standards. Strengthened controls together with border security and market surveillance alongside public awareness initiatives will help Sri Lanka to control whitening product imports and protect consumers while stopping dangerous chemicals and promoting ethical marketing practices.

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SUSTAINABLE LOGISTICS IN ENSURING RESILIENT SUPPLY CHAINS IN A VOLATILE GLOBAL ECONOMY

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Abstract

With the ever-changing situational crises, such as pandemic situations, economic uncertainties, and climate change, maintaining and ensuring resilient supply chains has become a major problem in the world of logistics. Owing to the same, various sustainable logistics practices have emerged to facilitate environmental responsiveness as well as remedy the aforementioned situations. This research will focus its scope on enhancing the efficiency and flexibility of the logistics process while ensuring minimum environmental impact. The key strategies will include increasing efficiency in transportation, integration of modern technology, integration of circular economic principles and emphasising the importance of collaborations among the supply chains. This study will illustrate how these sustainable logistics practices will empower the supply chains to be resilient and result in the smooth and continuous run of the business organisations in the volatile global environment.

Keywords: Environmental impact, resilient supply chains, sustainable logistics

Introduction

With the advancement of technology and the evolution of various industrial fields, the global economy has evolved throughout the years, making the world more sophisticated and raising a high demand for robust supply chains. However, in recent years, the global economy experienced various setbacks for the first time in history. The pandemic situation was the first major hit to the global economy, where it resulted in shutdowns and isolating various economies throughout the world, affecting almost every supply chain. Following the pandemic, various disturbances between nations led to war situations and civil unrest. Yet the evolution of the global economy has not ceased, and the demand for robust supply chains has increased more than ever.

1. Resilient supply chains

In view of undertaking the aforesaid challenges, the requirement of a resilient supply chain is crucial. A "resilient supply chain" can be defined as a supply chain which can withstand, adapt and recover from unforeseen situations which affect the smooth functioning of the supply chain, such as natural disasters, geopolitical conflicts, etc. This is a crucial factor in day economic activities, as most of the changes are unforeseen, and if the activities are disrupted as a result of unforeseen disasters, a relative setback could be expected in terms of the economy. A resilient supply chain possesses the following qualities:

a. **Flexibility**. The ability to adapt to various unpredictable circumstances, such as supplier noncompliance and changes in consumer trends.

b. **Visibility**. The ability of real-time monitoring and tracking of goods inventory and orders from one end to another enables the businesses or the end users to base their decisions on data and also enables the identification of problems prior.

c. **Diversification**. A resilient supply chain consists of more than one supplier for each and every good or service they procure. These suppliers are based in various geographical regions, and they utilise different modes of transportation.

d. **Inventory optimisation**. Inventories are maintained at an optimum level, reducing the warehousing or storage costs while keeping adequate stocks to meet the demand and contingency stocks to meet the unexpected.

The Role of Sustainable Logistics in Supply Chains

Sustainable logistics refers to the practice of organising and controlling the supply of goods and services along with information in a way that minimises the harmful effects caused to the environment, effectively utilises resources and promotes social responsibility throughout the entire supply chain. The aspects of sustainable logistics can be described as follows:

1. **Environmental responsibility**

The main objective of sustainability is to reduce the harm done to the environment and preserve the environment for future generations. In making the supply chain sustainable, the users should mainly consider the effect done to the environment and make the necessary amendments.

2. **Social responsibility**

Preserving the environment alone will not result in sustainability. The society or the communities should also be engaged so that the environment will be protected while the communities are being empowered and activated.

3. Economic efficiency

Sustainable logistics motivates the users to achieve the optimum utilisation of resources, thereby reducing wastage and achieving efficiency.

Benefits of Sustainable Logistics in a Resilient Supply Chain

Sustainable logistics practices provide a wide range of environmental, social, and economic benefits, which contribute to reducing operational costs, improving regulatory compliance, enhancing corporate reputation, and fostering long-term sustainability.

1. Environmental benefits

Through sustainable logistics, the emission and consumption of fuel can be reduced, as this process will include environmentally friendly transportation methods such as electric vehicles and hybrids. Further, as the routes are selected with the analytical data, congestion and potential hazards can be avoided. These practices will also ultimately reduce the carbon footprint left by humans.

Implementation of disposable or greener packaging will enhance environmental responsibility. As these are widely available and are at low prices, they are ideal for large commercial usage.

Further, through reusing practices or green packaging, various secondary costs, which are incurred for waste disposal, could be avoided. As the materials are reused until their deterioration, maximum utilisation of resources could also be achieved.

These practices will ultimately reduce the costs incurred for transportation insurance and other costs incurred in the transporting of goods, providing a cost advantage to the business itself. As businesses need to comply with the environmental regulations which are imposed by various institutions, engaging in sustainable logistics will automatically pave the pathway for the same.

2. Social benefits

Overall, working conditions could be improved, as through the utilisation of sustainable practices, there will be a cost saving. Therefore, the same can be utilised for the improvement of the quality of the work life, and various training could also be given. Further, as green practices are used, the employees feel that they are also supporting keeping the environment for future generations. Moreover, the health of the employees will also be ensured, and inverse cases the same will provide a cost advantage, as the costs incurred as medical expenses will be greatly reduced. These conditions will also result in high employee retention rates.

Local communities will benefit as the resources which have the most cost advantage will be utilised. Thereby resulting in an increase in the economic status of the local community as well. This will also act as a marketing strategy, as the goodwill of society could be gained through this method.

As the organisations are engaged in green logistics, no additional corporate social responsibility programmes are required to be conducted. And the organisations will be engaged in said course in real-time.

3. Economic benefits

The main advantage that an organisation could achieve through engaging in sustainable logistics is the cost advantage. Through route optimisation, the mode or the vehicle with the least cost will be selected, and the shortest safe route with relatively low disturbances and threats will be utilised. Adding an extra layer of protection.

Inventory management will be done purely based on the just-in-time and just-in-case strategies. Therefore, no additional cost for storing, warehousing and transportation will be required.

Engaging in green logistics practices will also result in reducing legal fees and penalties, as compliance with the legal framework will always be ensured. Further incentives could also be gained by engaging in green practices.

The competition in the market could also be well-regulated and dominated, as consumers will be prone to use products which are processed from sustainable practices. Further through these procedures, the consumers will feel that the respective company not only produces good quality products but also thinks about the planet.

Technology is used in sustainable and resilient supply chains

1. Internet of Things

Data is gathered in real-time, enabling consumers and suppliers to track and make decisions. These data could be beneficial in mitigating risks as well as costs.

2. Analytical data

Data collected from various sources provides various forms of insight to determine the cost efficiency and the overall efficiency of the supply chain while considering sustainability.

3. Artificial Intelligence

The modern trend of integrating artificial intelligence has made the users a hassle-free environment where both suppliers and end users can determine each and every step of the supply process.

Strategic Integration of Sustainability and Resilience into Supply Chains

Four main strategies could be identified in view of integrating sustainability and resilience into supply chains.

1. Collaboration with suppliers

Collaboration of suppliers is a vital factor in ensuring that suitable practices are met throughout the supply chain. If the suppliers are not willing to cooperate with the same sustainability, nor resilience can be achieved.

Organisations could have integrated green practices, such as low carbon emissions, and the factor of contribution gained from the local communities as criteria for the selection of suitable suppliers.

2. Diversification

Businesses should be encouraged to diversify their supply sources so that monopoly situations can be avoided. This will also result in a cost advantage to the business. Further alternative suppliers could also be recovered from the process.

3. Transparency

Transparency throughout the supply chain should be ensured so that weaknesses can be identified and relevant remedial measures can be taken in advance. Further risks can also be identified beforehand, ultimately making it another cost advantage.

4. Continuous improvement

Evaluations should be carried out at regular intervals so that resilience can be ensured.

Future Trends

With the increasing demand for electric vehicles, one could determine that the transportation sector is rapidly moving towards a zero-emission concept. Therefore, achieving sustainability through a resilient supply chain will not be a major issue in the future.

Artificial intelligence is integrated into systems where routes, mode warehousing, reorder levels, and all other major logistic decisions are being made.
Warehousing is also moving towards sustainable materials, where the storage can be provided with increased protection with optimum utilisation of resources.

Conclusion

In conclusion, sustainable logistics plays a pivotal role in ensuring the resilience of supply chains in today's volatile global economy. By integrating sustainable practices such as reducing emissions, optimising resource use, and fostering responsible sourcing businesses can mitigate risks, reduce costs, and enhance their long-term viability. Engaging with suppliers to embed sustainability throughout the supply chain further strengthens this resilience, creating a more adaptive and efficient network that can withstand economic, environmental, and geopolitical disruptions. As sustainability becomes an increasing priority for both consumers and regulators, companies that invest in sustainable logistics not only protect their operations but also enhance their competitive advantage and reputation. Ultimately, sustainable logistics is not just a strategy for minimising environmental impact; it is a vital pathway to building robust, future-proof supply chains that are better equipped to thrive in an uncertain and dynamic global landscape.

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INNOVATING FOR A GREENER FUTURE: SUSTAINABLE LOGISTICS STRATEGIES FOR REDUCING CARBON FOOTPRINTS IN GLOBAL SUPPLY CHAINS

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Abstract

In light of the increasing environmental concerns in the globe, ethical supply chain management is increasingly reliant on sustainable logistics. Logistics processes may have a substantial impact on greenhouse gas (GHG) emissions and other environmental issues, despite being essential to ensuring the timely and efficient movement of goods across international markets. Because of the growing need to reduce the carbon footprint of logistics, companies and policymakers are searching for innovative solutions to integrate environmental stewardship with operational efficiency. In order to reduce emissions and increase environmental performance in global supply chains, this study looks at a variety of sustainable logistics strategies. Among the primary areas of concentration are the introduction of electric vehicles and alternative fuels, the use of data analytics for real-time and predictive decision-making, the adoption of sustainable packaging solutions, and route optimization to lower fuel use. The paper also examines energy-efficient warehousing practices, multimodal transportation networks, and carbon offsetting programs as crucial components of an all-encompassing green logistics strategy. Through an analysis of recent industry statistics and current case studies, this paper provides a strategic framework for integrating sustainability into logistics operations. It highlights the environmental benefits of these practices as well as their potential to support cost cutting, legal compliance, and competitive differentiation. The report also highlights the ways in which digital technologies and cross-sector collaboration support the transition to low-carbon logistics systems. The findings contribute to the ongoing discussion on sustainable supply chain management by offering researchers, logistics experts, and industry stakeholders' useful insights and policy recommendations. In order to achieve long-term economic and environmental resilience, the research ultimately advocates for a creative, progressive approach to sustainable logistics.

Keywords: Greenhouse gas, sustainable logistics, carbon footprint

Introduction

In today's global economy, supply chains are crucial to the production and distribution of products and services. However, these complex networks play a significant part in environmental degradation; in 2020, the transportation sector alone accounted for

more

than 24% of global CO_2 emissions (SEKO Logistics, 2023). This alarming statistic highlights the pressing need for supply networks to implement sustainable logistics techniques in order to lower their carbon impact.

The term “green logistics,” sometimes referred to as “sustainable logistics,” describes a range of methods meant to enhance the environmental performance of supply chain operations. Important strategies include adopting eco-friendly packaging alternatives, embracing alternative fuels and electric cars, optimizing transportation networks, and leveraging digital technologies to boost productivity (SEKO Logistics, 2023). For example, firms are investing more money on fleets of electric vehicles in a bid to cut transportation-related emissions. Amazon just placed the largest-ever order for electric trucks in the UK in an effort to lessen the carbon footprint of its delivery services (The Guardian, 2025).

Using green logistics approaches has many benefits beyond just helping the environment. These methods can lead to considerable cost reductions through improved fuel efficiency and waste reduction. Socially, they enhance a brand’s standing and meet consumers’ growing need for businesses that uphold environmental responsibility. Additionally, by promoting regulatory compliance with stringent environmental regulations, sustainable practices reduce the risk of legal fines (SEKO Logistics, 2023). Many multinational corporations now realize that, in addition to being ethically right, maintaining a sustainable supply chain is also beneficial from a commercial perspective in a market that is growing more environmentally conscious.

Despite the clear advantages, the transition to sustainable logistics is not without its challenges. High upfront expenditures, technological limitations, and the need for industry-wide collaboration are significant barriers. For example, because of the uncertainty around the cost and availability of green fuels, shipping companies have made investments in dual-fuel ships as a hedge during the transition phase (Reuters, 2024). Furthermore, the lack of consistent regulations and incentives for the use of green fuel hinders the logistics sector’s adoption of sustainable practices. Smaller firms find it especially difficult to access green technology due to budgetary constraints and a lack of technical expertise.

Numerous businesses have demonstrated that these challenges can be overcome, nevertheless. For instance, Amazon has committed to achieving net-zero carbon emissions by 2040 and has made real investments in electric delivery trucks and renewable energy. In a similar vein, Unilever has collaborated with logistics firms to implement low-emission transportation options and optimize supply chain operations through data-driven decision-making (PL Global, 2023). These illustrations demonstrate how strategic planning, investment, and stakeholder involvement can effectively integrate sustainable logistics into global supply chains. As governments, investors, and consumers demand environmental accountability, the need for innovative solutions is growing.

Data Analytics and Digitization in Logistics

1. Analytics for Prediction

Predictive analytics helps businesses estimate future demand and make the necessary adjustments to inventory levels. Avoiding emergency restocking, reducing unnecessary shipping, and controlling overproduction through precise forecasting all contribute to a lower carbon footprint (Disk.com, 2023). Consequently, companies may align their production and delivery schedules with actual market demand.

2. Optimization of Routes

Advanced route planning software uses real-time weather, traffic, and fuel data to design the most efficient delivery routes. UPS's On-Road Integrated Optimization and Navigation (ORION) system is a noteworthy example; it is claimed to save fuel consumption by 10 million gallons per year (Supply Chain Brain, 2023). Route optimization reduces idle time, cuts mileage, and boosts fleet efficiency.

3. Fleet Management Driven by IoT

IoT driven fleet management uses connected sensors, cloud computing, and real-time data analytics to maximize vehicle performance, save expenses, and increase safety. By combining GPS trackers, fuel monitors, and diagnostic tools, fleets may get the most recent data on routes, engine health, driver behavior, and cargo conditions. Predictive maintenance alerts help prevent problems, while AI-powered route changes use less fuel. This seamless IoT connection turns logistics into a more data-driven, intelligent ecosystem that enhances efficiency, sustainability, and operational management.

Transitioning to Small Production Transportation

1. Hybrid and Electric Automobiles

Electrification is one of the biggest advances in logistics. For example, following an agreement with Rivian, Amazon began deploying its 100,000 electric vehicles in strategic cities (The Guardian, 2025). Electric vehicles (EVs) are ideal for last-mile delivery in urban areas since they don't produce any exhaust emissions.

2. Alternatives to Hydrogen and Biofuel

Hydrogen fuel cells and biodiesel are good substitutes for heavy-duty freight and long-distance transportation. Only water vapor is produced by hydrogen-powered trucks, such as those created by Hyundai and Nikola. With just slight adjustments to current engines, biofuels made from waste materials may take the place of diesel, simplifying the transition for many businesses (Supply Chain Brain, 2023).

Implementation Multimodal and Green Transportation

Through the integration of many transportation modes, including road, rail, and sea, multimodal logistics optimizes efficiency and reduces emissions. Rail transit produces around 75% fewer greenhouse gasses per ton-mile than automobile transportation (AP News, 2023). By adopting rail for long-distance delivery, companies like Coca-Cola have lessened their need on vehicles (Supply Chain Brain, 2023). Others, like Grain de Sail, use wind-powered ships to deliver products, reviving a zero-emissions means of transportation (AP News, 2023).

Sustainable Packing and Freight Optimization

Packaging has a big impact on how a product affects the environment. Lightweight, biodegradable, or reusable materials contribute to lower emissions during manufacturing and shipping. IKEA shifted to paper-based packaging in order to reduce weight and improve recyclability (Supply Chain Brain, 2023). Additionally, more containers are used by redesigned packaging that allow for more compact packing, which leads to fewer shipments.

Energy Efficient Warehousing

Warehouses need a lot of electricity, mostly for lighting, heating, and cooling. Emissions may be considerably decreased by energy-efficient upgrades including solar panels, motion-activated LED lights, and HVAC optimization. Amazon has begun installing rooftop solar panels at their fulfillment centers as part of their goal to run their business entirely on renewable energy (Supply Chain Brain, 2023). Additionally, automated systems increase efficiency and security by reducing the distance that workers and forklifts must travel.

Carbon Offsetting and Environmental Certification

1. Offsets of Carbon

Carbon offsetting involve financing environmental projects like methane collection, clean energy, and reforestation in order to offset unavoidable emissions. DHL is a carbon-neutral shipping company that funds authorized reforestation and renewable energy projects across the world (Supply Chain Brain, 2023).

2. Standards and Certifications

Certifications such as LEED (green building) and ISO 14001 (environmental management) confirm a company's environmental performance and offer foundations for sustainability initiatives. Adopting these standards increases stakeholder transparency and confidence.

Green Collaboration and Shared Logistics

1. Cooperative Distribution

By combining logistical resources like warehouses, vehicles and data businesses may save needless trips and underused capacity. For example, merchants nearby can co-load goods to cut down on empty miles (Disk.com, 2023).

2. Platforms for Digital Freight

Platforms such as Uber Freight and Flexport link shippers with underused transport providers. These solutions reduce emissions per cargo by enhancing vehicle usage and decreasing the number of vehicles on the road.

Case Studies

1. Amazon UK

In 2025, Amazon UK placed its largest purchase for electric HGVs, importing 140 electric Mercedes-Benz trucks and eight 40-ton Volvo Lorries (The Guardian, 2025). The investment aims to replace diesel cars with electric ones and move some freight to rail in order to achieve net-zero emissions by 2040.

2. DHL Go Green

DHL's Go Green initiative aims to attain net-zero emissions from logistics by 2050. Additionally, it offers delivery that is carbon neutral. With its utilization of carbon offsetting, electric cars, and renewable energy in its logistics facilities, DHL is a global leader in sustainable logistics.

3. Restructuring the IKEA Supply Chain

IKEA has restructured its logistics with a focus on sustainability by implementing ecological packaging, maximizing container capacity and moving to rail and sea delivery. These changes helped the company reduce its carbon emissions by almost 14% across its supply chain (Supply Chain Brain, 2023).

Conclusion

In an era of environmental challenges and growing awareness of climate change, the logistics and supply chain sector is crucial to building a more sustainable future. This article has looked at the innovative strategies being employed by companies all around the world to reduce their carbon footprints while maintaining strong and efficient supply networks. Through the use of digital technologies like artificial intelligence and

the Internet of Things, as well as the simplification of transportation routes and the use of renewable energy, these sustainable logistics strategies are transforming traditional models into more ecologically conscious and conscientious operations.
Beyond public opinion or legal compliance, sustainability is becoming a more important component of logistics' long-term economic viability and competitiveness. The increasing demands for accountability and openness from stakeholders and customers are driving businesses to adopt greener practices throughout the value chain. This shift has become more than simply a fad because of the pressing need to combat climate change and save natural resources for next generations.

Innovative tactics including carbon offsetting, electric and hybrid vehicle fleets, green warehousing, and circular logistics models are transforming global supply chains. These programs not only lessen environmental impact but also provide cost savings, risk reduction, and enhanced brand value.

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INNOVATING FOR A GREENER FUTURE: SUSTAINABLE LOGISTICS STRATEGIES FOR REDUCING CARBON FOOTPRINTS IN GLOBAL SUPPLY CHAINS

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Abstract

Sustainable logistics is becoming a vital component of ethical supply chain management in the face of growing environmental issues worldwide. Although they are necessary to guarantee the prompt and effective transportation of commodities across international markets, logistics activities can significantly contribute to greenhouse gas (GHG) emissions and other environmental effects. Businesses and legislators are looking for creative ways to strike a balance between environmental stewardship and operational efficiency as a result of the increased desire to lower the carbon footprint of logistics. A wide range of sustainable logistics techniques are examined in this study with the goal of lowering emissions and improving environmental performance in international supply chains. The use of data analytics for real-time and predictive decision-making, route optimization to reduce fuel consumption, the introduction of electric cars and alternative fuels, and the adoption of sustainable packaging solutions are some of the main areas of focus. As essential elements of a comprehensive strategy for green logistics, the report also looks at multimodal transportation networks, carbon offsetting programs, and energy-efficient warehousing techniques. This study offers a strategic framework for incorporating sustainability into logistics operations by analyzing recent industry statistics and current case studies. It draws attention to these practices' advantages for the environment as well as their capacity to promote cost reduction, legal compliance, and competitive differentiation. The study also emphasizes how cross-sector cooperation and digital technology facilitate the shift to low-carbon logistics systems. By providing researchers, logistics professionals, and industry stakeholders with practical insights and policy recommendations, the findings add to the continuing conversation on sustainable supply chain management. In the end, the study promotes an innovative, forward-thinking strategy for sustainable logistics as a means of attaining long-term economic and environmental resilience.

Keywords: Sustainable logistics, carbon footprints

Introduction

Supply chains are essential to the manufacturing and distribution of goods and services in the modern global economy. Nonetheless, these intricate networks have a major role in environmental deterioration; in 2020, the transportation industry alone was responsible for over 24% of worldwide CO_2 emissions (SEKO Logistics, 2023). This concerning figure emphasizes how urgently supply networks must adopt sustainable logistical practices to reduce their carbon footprint.

Green logistics, also known as sustainable logistics, refers to a variety of techniques intended to improve supply chain operations' environmental performance. Implementing eco-friendly packaging options, embracing electric vehicles and alternative fuels, streamlining transportation networks, and utilizing digital technology to increase efficiency are all important tactics (SEKO Logistics, 2023). For example, businesses are spending more money on fleets of electric vehicles in an effort to lower transportation-related emissions. In an attempt to reduce the carbon footprint of its delivery services, Amazon just placed the largest-ever order for electric lorries in the UK (The Guardian, 2025).

Beyond protecting the environment, there are several advantages to using green logistical techniques. Through increased fuel economy and waste reduction, these techniques can result in significant cost savings. Socially, they improve a brand's reputation and satisfy customers' increasing need for companies that practice environmental responsibility. Furthermore, sustainable practices lower the danger of legal penalties by facilitating regulatory compliance with strict environmental rules (SEKO Logistics, 2023). Nowadays, a lot of global firms understand that managing a sustainable supply chain is not only morally required, but also advantageous from a business standpoint in a market that is becoming more environmentally sensitive.

The shift to sustainable logistics is not without its difficulties, despite the obvious benefits. Significant obstacles include high upfront costs, technological constraints, and the requirement for industry-wide cooperation. For instance, shipping corporations have invested in dual-fuel vessels as a hedge during the transition period due to the uncertainties around the pricing and availability of green fuels (Reuters, 2024). Furthermore, the logistics industry's adoption of sustainable practices is hampered by the absence of uniform rules and incentives for the use of green fuel. Accessing green technologies is particularly challenging for smaller businesses because of financial limitations and a lack of technical know-how.

However, many organizations have shown that it is possible to overcome these obstacles. For example, Amazon has made a commitment to reach net-zero carbon emissions by 2040 and has made tangible investments in renewable energy and electric delivery trucks. Similar to this, Unilever has partnered with logistics companies to streamline supply chain operations using data-driven decision-making and deploy low-emission transportation solutions (PL Global, 2023). These examples show how sustainable logistics may be successfully incorporated into international supply chains through stakeholder participation, investment, and strategic planning.

Innovative solutions are becoming more and more necessary as governments, investors, and consumers demand environmental accountability. By improving transparency, cutting down on inefficiencies, and bolstering data-driven sustainability objectives, digital technologies like artificial intelligence, block chain, and the Internet of Things (IoT) are essential to allowing greener logistics. By incorporating these technology into logistics networks, companies may proactively monitor pollution, optimize routes, and proactively.

Data Analytics and Digitization in Logistics

1. Predictive Analytics

Businesses can forecast future demand and adjust inventory levels appropriately with the help of predictive analytics. A smaller carbon footprint is achieved by avoiding emergency restocking, cutting down on needless shipments, and minimizing overproduction through accurate forecasting (Disk.com, 2023). As a result, businesses may match their delivery and production plans to the real demand in the market.

2. Route Optimization

To create the most effective delivery routes, sophisticated route planning software makes use of real-time weather, traffic, and fuel data. One notable example is UPS's On-Road Integrated Optimization and Navigation (ORION) system, which is said to cut fuel use by 10 million gallons annually (Supply Chain Brain, 2023). Route optimization increases fleet productivity, lowers mileage, and minimizes idle time.

3. IoT-Driven Fleet Management

IoT-driven fleet management optimizes vehicle performance, lowers costs, and improves safety by utilizing cloud computing, real-time data analytics, and linked sensors. Fleets can obtain up-to-date information on routes, engine health, driver conduct, and cargo conditions by integrating GPS trackers, fuel monitors, and diagnostic tools. AI-powered route modifications reduce fuel usage, and predictive maintenance warnings help avoids malfunctions. Logistics is transformed into a more intelligent, data-driven ecosystem by this smooth IoT integration, which improves operational control, sustainability, and efficiency.

Transitioning to Low-Emission Transportation

1. Electric and Hybrid Vehicles

One of the most significant developments in logistics is electrification. For instance, Amazon started deploying its 100,000 electric trucks in key cities after placing an order with Rivian (The Guardian, 2025). Since they emit no tailpipe emissions, electric vehicles (EVs) are perfect for last-mile delivery in cities.

2. Hydrogen and Biofuel Alternatives

For heavy-duty freight and long-distance haulage, hydrogen fuel cells and biodiesel offer viable alternatives. Hydrogen-powered trucks, like those developed by Hyundai and Nikola, produce only water vapor. Biofuels derived from waste materials can replace diesel with minor modifications to existing engines, making the transition easier for many firms (Supply Chain Brain, 2023).

Embracing Multimodal and Green Transportation

Multimodal logistics maximizes efficiency and lowers emissions by integrating several modes of transportation, such as road, rail, and sea. Compared to vehicle transportation, rail transport generates about 75% fewer greenhouse gases per ton-mile (AP News, 2023). Businesses such as Coca-Cola have reduced their reliance on trucks by using rail for long-distance shipping (Supply Chain Brain, 2023). Others, such as Grain de Sail, revive a zero-emissions mode of transportation by shipping goods aboard wind-powered vessels (AP News, 2023).

Sustainable Packaging and Load Optimization

The environmental impact of a product is greatly influenced by its packaging. Materials that are lightweight, biodegradable, or reusable help reduce emissions during production and transportation. To cut weight and increase recyclability, IKEA switched to paper-based packaging (Supply Chain Brain, 2023). Additionally, redesigned packages that enable more compact packing make use of more containers, which results in fewer shipments.

Energy Efficient Warehousing

Electricity is used extensively in warehouses, mostly for heating, cooling, and lighting. Upgrades that use less energy, such as solar panels, motion-activated LED lighting, and HVAC optimization, can significantly reduce emissions. As part of their objective to operate entirely on renewable energy, Amazon has started building rooftop solar panels at their fulfillment locations (Supply Chain Brain, 2023). Automated systems also shorten the distance that personnel and forklifts must travel, increasing productivity and security.

Carbon Offsetting and Environmental Certification

1. Carbon Offsets

To offset inevitable emissions, carbon offsetting entails funding environmental initiatives like methane capture, clean energy, and reforestation. Worldwide approved reforestation and renewable energy initiatives are funded by DHL, a carbon-neutral shipping option (Supply Chain Brain, 2023).

2. Certifications and Standards

Certifications like ISO 14001 (Environmental Management) and LEED (green building) provide frameworks for sustainability efforts and validate a company's environmental performance. Adopting such standards builds trust and transparency with stakeholders.

Green Collaboration and Shared Logistics

1. Collaborative Distribution

Companies can cut down on unnecessary journeys and unused capacity by pooling logistics resources including warehouses, cars, and data. To reduce empty miles, for instance, retailers in the same area can co-load packages (Disk.com, 2023).

2. Digital Freight Platforms

Shippers and underutilized transport providers are connected by platforms like as Uber Freight and Flexport. By reducing the number of trucks on the road and increasing vehicle utilization, these technologies lower emissions per shipment.

Case Studies

1. Amazon UK

Amazon UK placed its largest order for electric HGVs in 2025, bringing in eight 40-ton Volvo Lorries and 140 electric Mercedes-Benz trucks (The Guardian, 2025). In order to reach net-zero carbon by 2040, the investment intends to switch some freight to rail and replace diesel vehicles with electric versions.

2. DHL Go Green

By 2050, DHL's Go Green program seeks to achieve net-zero emissions from logistics. It also provides carbon-neutral shipping. DHL leads the market in sustainable logistics with its use of electric vehicles, carbon offsetting, and renewable energy in logistics facilities.

3. IKEA Supply Chain Overhaul

By switching to rail and sea transportation, making the most of container space, and introducing ecological packaging, IKEA has reorganized its logistics with an emphasis on sustainability. Throughout its supply chain, these adjustments contributed to a reduction in carbon emissions of more than 14% (Supply Chain Brain, 2023).

Conclusion

The logistics and supply chain industry is essential to creating a more sustainable future in a time of environmental difficulties and increased awareness of climate change. This publication has examined the cutting-edge tactics being used by businesses worldwide to lower their carbon footprints while preserving robust and effective supply chains. These sustainable logistics techniques are converting conventional models into more environmentally friendly and conscientious operations, from streamlining transportation routes and adopting renewable energy to utilizing digital technologies like artificial intelligence and the Internet of Things.

Sustainability is increasingly a crucial element of long-term economic viability and competitiveness in logistics, going beyond public perception or regulatory compliance. Businesses are being pushed to implement cleaner practices across the value chain by stakeholders' and consumers' growing expectations for accountability and transparency. The urgent need to fight climate change and protect natural resources for future generations has caused this transition to become more than just a trend.

Global supply chains are changing as a result of innovative strategies including carbon offsetting, electric and hybrid car fleets, green warehousing, and circular logistics models. These initiatives offer cost savings, risk reduction, and increased brand value in addition to reducing environmental harm. Businesses can open up new business prospects and make a beneficial impact on the environment by incorporating sustainability into their basic logistics strategy.

But there are obstacles in the way of the shift to sustainable logistics. Progress can be hampered by high upfront costs, technological obstacles, and a lack of globally defined standards. However, these obstacles can be removed with greater cooperation between governments, businesses, and IT developers. Accelerating this shift will require public-private collaborations, supportive policies, and education about sustainable practices.

In conclusion, it is both necessary and possible to move toward more environmentally friendly global supply chains. Sustainable logistics will develop into a moral need as well as a competitive advantage as businesses continue to innovate and adapt. Businesses may set the standard for a future where environmental stewardship and economic growth coexist by embracing ecologically responsible practices and committing to carbon reduction. Although the trip calls for commitment, funding, and teamwork, the long-term advantages for the environment, people, and financial gain are indisputable. Sustainable logistics is the way of the future for global supply chains, not just a decision.

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SUSTAINABLE LOGISTICS PRACTICES: BUILDING A GREENER SUPPLY CHAIN

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Abstract

This article explains how global logistics is transforming to become sustainable by examining key practices that reduce environmental impact while optimizing operational efficiency. Since transport and warehousing are substantial contributors to CO_2 emissions, businesses are considering green initiatives such as alternative fuel vehicles, intermodal transport, AI-driven optimization, energy-harvesting warehousing, and circular supply chains. Amazon's solar roof warehouses, FedEx's electric vehicle plans, and Walmart's river barge logistics are a few notable examples. The intersection of digital technologies like blockchain, IoT, and predictive analytics is driving more intelligent, low-emission operations. Policy incentives and industry collaborations, on the other hand, are accelerating the transition to sustainable logistics. The paper concludes that companies embracing the changes will not only reduce carbon footprints but also gain long-term cost savings, regulatory compliance, and competitive differentiation in a low-carbon economy.

Keywords: Sustainable logistics, green supply chain, circular economy, energy efficiency, low-carbon transport

Introduction

The global logistics sector plays a vital role in facilitating trade and economic expansion, it also makes a substantial contribution to environmental deterioration. The International Transport Forum estimates that road freight alone is responsible for roughly 40% of emissions related to logistics, and that freight transport contributes approximately 8% of global CO_2 emissions. Businesses and governments are facing mounting pressure to implement sustainable logistics practices that minimize environmental impact while preserving efficiency as concerns about climate change growth (Gani, 2017).

This article examines important sustainable logistics tactics, such as technology-driven optimization, circular supply chains, energy-efficient warehousing, and green transportation. Businesses can contribute to global sustainability goals while achieving cost savings, regulatory compliance, and improved brand reputation by putting these practices into practice.

Transportation: Reducing Emissions in Freight Movement

Transportation is essential to international logistics, it also contributes the most to supply chain carbon emissions. Nearly 40% of all transport-related CO_2 emissions come from freight transportation, with road freight being the main source of pollution, according to the International Energy Agency (IEA). Businesses and governments are implementing green transportation strategies, such as intermodal shifts, smart logistics, alternative fuels, and last-mile innovations, to counteract this.

1. Sustainable Logistics Practices: A Deep Dive into Energy Efficiency, Circular Systems, and Digital Innovation

The logistics sector is undergoing a profound transformation as environmental concerns and operational efficiencies converge to drive sustainable innovation. Across the transportation and supply chain spectrum, companies are implementing ground breaking solutions that reduce carbon footprints while maintaining - and often enhancing - business performance. This comprehensive exploration examines the most impactful sustainable logistics practices reshaping global supply networks (Nagy, 2023).

2. Revolutionizing Freight with Alternative Fuel Vehicles

One of the biggest changes in sustainable logistics is the switch from conventional diesel to alternative fuel vehicles. Due to significant commitments from industry leaders, electric vehicles are quickly becoming more and more popular for short-distance and urban applications. The largest commercial EV order in history was placed by Amazon with Rivian for 100,000 electric delivery vans, and DHL's Street Scooter EVs show that electric fleets are operationally viable for last-mile delivery. FedEx's commitment to operating an entirely electric package fleet by 2040 highlights the industry's trajectory. Long-distance applications are still hampered by battery technology limitations, though, and hydrogen fuel cells are showing promise as a remedy. Hydrogen-powered trucks with 500–900 km range, quick refuelling, and true zero-emission operation are being developed by companies like Nikola Motors. In the meantime, temporary fixes like renewable

3. Intermodal Shifts: Maximizing Efficiency in Freight Movement

A fundamental rethinking of freight movement is reflected in the strategic shift toward intermodal transport. Since rail transport emits 75% less CO_2 per ton-mile than trucks, it has emerged as a key component of sustainable logistics plans. UPS's rail network and Maersk's "Ecological" rail services in Europe serve as examples of how significant logistics companies are reorganizing their business models. With barge shipping emitting up to 80%

less than truck transport, waterway transport offers even higher efficiencies. The potential of inland waterways is demonstrated by Walmart's Mississippi River barge operations and the EU's Naiades III program. These solutions, however, are constrained by infrastructure, especially in areas with underdeveloped rail networks, such as Africa and portions of Asia. Additionally, the last-mile reliance on road transportation creates logistical challenges that call for creative solutions.

4. AI-Driven Optimization: The Smart Logistics Revolution

Logistics operations are being revolutionized by artificial intelligence thanks to its unparalleled optimization capabilities. In order to reduce fuel consumption, sophisticated route planning algorithms from companies like Trimble and Google OR-Tools examine a variety of factors, including current traffic and meteorological patterns. Some fleets report a 15-20% decrease in empty miles, indicating the significant impact. The industry's persistent problem of empty truck runs, which make up 20% of freight miles, is addressed by digital freight networks like Convoy and Uber Freight, which use AI to significantly increase load matching efficiency. The concrete advantages of these technologies are demonstrated by DHL's deployment of AI-powered routing, which has resulted in an 8% annual reduction in fuel consumption. These systems are further improved by the incorporation of IoT devices, which allow for dynamic adjustments and real-time monitoring that continuously optimize operations (Mr. Bipul Bera*1, 2025).

5. Last-Mile Innovation: Solving the Urban Delivery Challenge

Particularly in crowded urban settings, the last leg of delivery poses special sustainability challenges. In response, businesses are coming up with innovative solutions that blend technology with different delivery channels. UPS's e-Bike program and DHL's Cubicycle show how human-powered delivery can reduce emissions in urban areas by up to 50%. Although there are still operational and regulatory obstacles to overcome, drone delivery services like Amazon Prime Air and Wing by Alphabet represent a technological advancement. Micro-fulfilment strategies that put inventory closer to end users may be the most revolutionary. Delivery times as short as 10 minutes are now possible thanks to Walmart's local fulfilment centres and the dark store model, which was pioneered by Gorillas and other rapid delivery services. These measures are also lowering transportation emissions. Together, these developments tackle the crucial.

6. Energy-Efficient Warehousing: Rethinking Storage Infrastructure

Energy-intensive buildings are giving way to efficient models as modern warehouses undergo their own sustainability revolution. With Amazon pledging to run its fulfilment network entirely on renewable energy and IKEA putting solar panels on 90% of its warehouse rooftops, renewable energy integration has become a standard practice among industry leaders. While LED lighting with motion sensors can reduce electricity consumption by 70%, automation technologies such as Automated Storage & Retrieval Systems (AS/RS) are reducing energy waste by up to 30%. More intelligent methods of inventory management are used in conjunction with these technological developments. Material waste has been cut by 30% thanks to Amazon's Frustration-Free Packaging initiative, and Just-in-Time inventory systems, which have been refined by firms like Dell and Toyota, reduce the need for storage and the energy it uses. When combined, these developments are changing the definition of sustainable warehousing in the modern supply chain.

7. Circular Supply Chains: Closing the Loop on Waste

Traditional linear models have been fundamentally reimagined by the idea of circular supply chains. Prominent businesses are putting advanced reverse logistics systems into place to extend the life of materials. While Patagonia's Worn Wear program has saved countless garments from landfills through refurbishment and resale, Apple's robotic disassembly systems can recover valuable materials from 200 iPhones per hour. Sustainable sourcing methods are equally important; Walmart's Project Gigaton initiative and Nestlé's pledge to use palm oil free of deforestation show how supplier cooperation can spur systemic change. These circular approaches demonstrate that sustainability and profitability can work hand in hand by reducing their negative effects on the environment while also frequently revealing new sources of income and cost savings.

8. Digital Transformation: The Backbone of Sustainable Logistics

Supply chains are becoming more visible and efficient than ever thanks to digital technologies. Smart contracts automate adherence to sustainability standards, and blockchain solutions like IBM Food Trust are improving traceability and reducing food spoilage by 30%. With Zara's demand forecasting systems drastically cutting down on overproduction, predictive analytics is optimizing inventory levels. Through real-time monitoring, IoT-enabled fleet management systems like Shell's are increasing fuel efficiency by 15%. In addition to being more resilient and responsive to market demands, these digital tools are making supply chains more sustainable.

9. Policy and Collaboration: Accelerating Industry Transformation

Government rules and industry partnerships are becoming more and more crucial in promoting sustainable logistics. Fleet electrification is being accelerated by the U.S. Inflation Reduction Act's electric truck subsidies and the EU's Carbon Border Adjustment Mechanism, which offers financial incentives for low-carbon supply chains. LEED certification has emerged as a standard for environmentally friendly warehouse design, and industry initiatives such as the Smart Freight Centre's GLEC Framework are standardizing emissions reporting. By working together, we are building an ecosystem that will support the growth and expansion of sustainable logistics practices.

The combination of these developments from digital enablement to circular models to alternative fuels creates the impression that the logistics industry is going through a significant transition. Although there are still implementation and scaling issues, the trend is clear: sustainable logistics is now a business necessity rather than an option.

Energy Efficient Warehousing & Smart Storage

As companies become aware of the substantial energy consumption and environmental impact of modern warehouses, a green revolution is taking place. Modern sustainable solutions are reimagining historically energy-intensive processes for material handling equipment, HVAC systems, and lighting. Prominent businesses are putting into practice all-encompassing energy efficiency strategies that integrate intelligent technology with the production of renewable energy. Nowadays, warehouse rooftops all over the world are covered in solar panels; some establishments, such as IKEA's distribution centres, produce all of their own electricity. Intelligent LED lighting with motion sensors can reduce electricity consumption by up to 70%, and advanced automation systems optimize energy use by minimizing unnecessary equipment operation. Innovative insulation materials and geothermal systems that reduce HVAC demands are revolutionizing temperature regulation. These changes are demonstrating financial viability in addition to environmental responsibility (Derpich, 2022).

1. Renewable Energy Integration

Many leading companies are transitioning warehouses to 100% renewable energy. IKEA, for example, has installed solar panels on 90% of its warehouse rooftops, generating enough clean energy to power operations. Some facilities also incorporate wind turbines and geothermal heating to regulate temperatures without fossil fuels. Amazon's fulfilment centres now use solar and wind energy, aiming for net-zero carbon by 2040.

2. Automated & Low-Energy Systems

Automation optimizes storage and retrieval procedures, which lowers energy waste. By eliminating needless movement, Automated Storage & Retrieval Systems (AS/RS) can reduce electricity consumption by as much as 30%. Furthermore, compared to conventional lighting, LED lighting with motion sensors ensures that lights are only turned on when necessary, saving 70% on energy use. These technologies have been implemented by companies such as Walmart and Prologis in an effort to reduce emissions and operating expenses.

3. Sustainable Packaging & Inventory Management

Over packaging increases shipping emissions and waste. By removing needless materials, Amazon's Frustration-Free Packaging initiative reduces waste by 30%. Toyota and Dell use Just-in-Time (JIT) inventory systems, which reduce storage requirements and warehouse energy consumption. Businesses can drastically lessen their environmental impact by optimizing packaging and stock levels.

Circular Supply Chains: Reducing Waste Through Reuse & Recycling

By designing products for longevity, reuse, and recycling, a circular supply chain reduces waste. Reverse logistics is used to recover materials, repair goods, and put them back into use. Repair initiatives and the sourcing of recycled materials are ways that businesses like Apple and Patagonia show this, lessening their impact on the environment while generating new revenue streams from recovered resources. Throughout the whole product lifecycle, this closed-loop system optimizes resource productivity (Vegter, 2020).

1. Reverse Logistics & Product Returns

Instead of discarding returned goods, companies like Apple use robotic disassembly (Daisy robot) to recover valuable materials from old iPhones. Patagonia's Worn Wear program refurbishes and resells used clothing, extending product lifecycles. These practices reduce landfill waste and lower the need for raw material extraction.

2. Sustainable Sourcing & Supplier Collaboration

Materials are sourced responsibly thanks to ethical procurement. While Walmart's Project Gigaton collaborates with suppliers to reduce 1 billion metric tons of CO_2 from its supply chain, Nestlé has pledged to use palm oil free of deforestation. These partnerships guarantee that sustainability requirements are fulfilled throughout the entire production process.

Digitalization & AI for Sustainable Logistics

Logistics operations are changing as a result of cutting-edge technologies like blockchain, AI, and IoT. IoT allows for real-time tracking, blockchain improves supply chain transparency, and AI optimizes routes and inventory. Smarter, more effective, and ecologically conscious supply chains for the digital age are produced by these innovations, which also lower costs, minimize waste, and enhance sustainability throughout the logistics ecosystem (Orelma, 2024).

1. Blockchain for Transparency

IBM Food Trust tracks food shipments in real-time, reducing spoilage by 30%. Smart contracts automate sustainability compliance, ensuring suppliers adhere to eco-friendly practices without manual oversight.

2. Predictive Analytics for Demand Forecasting

AI-driven forecasting, like Zara's inventory optimization, prevents overproduction, reducing waste and excess stock. This leads to leaner supply chains with lower energy and storage demands.

3. IoT & Smart Fleet Management

Shell's telematics systems monitor fuel consumption in real-time, improving efficiency by 15%. Predictive maintenance (used by Maersk) prevents breakdowns, reducing emissions from idling and inefficient routes.

Policy & Industry Collaboration

Strong legislative frameworks and industry collaboration are necessary for logistics to be sustainable. While industry alliances create standardized green practices, governments implement policies like carbon taxes and electric vehicle incentives to bring about change. Collectively, these initiatives promote innovation in global supply chains, establish accountability, and quicken the adoption of sustainable technologies for a low-carbon future.

1. Government Regulations & Incentives

The EU's Carbon Border Adjustment Mechanism (CBAM) imposes fees on high-emission imports, pushing companies toward greener alternatives. The U.S. Inflation Reduction Act (IRA) offers tax credits for electric trucks, accelerating the shift to zero-emission freight.

2. Industry Alliances & Green Certifications

By standardizing emissions reporting, the Smart Freight Centre's GLEC Framework aids businesses in comparing their progress. Prologis's and other LEED-certified warehouses adhere to strict energy efficiency guidelines, which lowers their operational carbon footprints.

Conclusion: The Future Of Sustainable Logistics

The logistics industry is undergoing a fundamental transformation as sustainability transitions from a voluntary initiative to a critical business imperative. Organizations that proactively implement comprehensive green strategies across their operations rom alternative fuel vehicles and renewable-powered warehouses to circular supply models and AI-enhanced efficiency will secure significant competitive advantages. These forward-thinking companies stand to benefit not just through reduced environmental impact, but also through substantial long-term cost reductions, improved regulatory compliance, and enhanced brand reputation among increasingly eco-conscious consumers.

Looking ahead, the logistics sector will be defined by three key technological revolutions: zero-emission transportation networks utilizing electric and hydrogen-powered fleets; smart warehouses powered by automation and renewable energy; and fully transparent supply chains enabled by blockchain tracking. These innovations will converge to create supply chains that are not only environmentally responsible but also more resilient, efficient, and responsive to market demands.

Businesses that adopt these sustainable logistics solutions will be better equipped to handle upcoming difficulties and support global decarbonisation initiatives as climate regulations become more stringent and customer expectations change. Beyond environmental stewardship, the transition offers a strategic chance to future-proof operations, unlock new efficiencies, and create a logistics infrastructure that can meet the demands of the low-carbon economy of the future. However, it also necessitates a significant investment and operational changes. Businesses that understand this necessity now will be at the forefront of the sector tomorrow.

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CHALLENGES AND OPPORTUNITIES TO TRANSFER TO ECO - FRIENDLY LOGISTICS IN SRI LANKA

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Abstract

Sri Lanka presents a very good opportunity to become a green logistics hub in South Asia. Simply put, it is located on path of global trade routes. However, the growth towards sustainability is hindered by issues including the old infrastructure, no renewability of energy resources, technological gaps, poor enforcement of policies, and the reluctance of stakeholders, especially those from the SMEs. With reference to some international and local examples such as DHL GoGreen initiatives and Dilmah Tea carbon neutralization via mini hydro projects, the article discusses the potential the public private partnerships, digitalization, renewable energy investment, and capacity building have in becoming change mediators. It proposes urgent actions toward establishing a nationwide policy framework, strengthening institutions, and collaboration among stakeholders so that Sri Lanka's logistics sector is aligned with global environmental standards and achieves carbon neutrality by 2050.

Keywords: Green logistics, sustainable supply chain, digitalization

Introduction

As global environmental concerns rise, the logistics industry is moving toward more sustainable and eco-friendly practices, and Sri Lanka is no exception. As an island nation strategically located along major international shipping routes, logistics is vital to Sri Lanka's economy, particularly through its reliance on imports, exports, and domestic transportation. However, the transition to green logistics in Sri Lanka faces several challenges. High operational costs, outdated infrastructure, and regulatory gaps make it difficult to implement environmentally friendly solutions. Ports like Hambantota, despite being situated on one of the world's busiest marine trade routes, remain underutilized due to low cargo volumes, high debt, poor hinterland connectivity, and a lack of value-added services. These factors limit Sri Lanka's ability to compete with established regional hubs such as Singapore, Dubai (Jebel Ali), and Malaysia's Port Klang, which benefit from world-class infrastructure and efficient management systems. Additionally, the lack of strong multimodal transport integration, such as railway and inland waterway connections, further restricts the country's logistics potential.

Despite these challenges, Sri Lanka's strategic location presents significant opportunities for enhancing its logistics sector, particularly through its main gateway, the Port of Colombo, which handles about 7 million TEUs annually and is ranked among the world's top container ports. Government initiatives, technological innovations, and the adoption of renewable energy solutions offer promising pathways for the development of sustainable logistics. By addressing structural inefficiencies, investing in modern infrastructure, and implementing cohesive policy reforms, Sri Lanka can leverage its geostrategic advantages to build a resilient, cost-effective, and environmentally sustainable logistics network. This transformation is essential not only for maintaining the country's competitiveness in global trade but also for supporting long-term economic growth and environmental stewardship.

Empowering Sri Lanka's Competitiveness in the Global Logistics Arena

Sri Lanka has a larger array of strategic measures to implement in order to bolster its position as a regional logistics hub:

1. Port capacity increase, road and rail link strengthening, and warehousing and distribution center modernization for efficient freight flow through modern roads.

2. Improve efficiency and reduce turnaround times using smart ports, blockchain trade documents, and AI enabled logistics solutions.

3. Public, private partnerships would mean government partnerships with foreign logistics corporations to increase investment into port expansion, inland freight corridors, and logistics parks.

4. Sustainable and Eco-friendly Logistics, develop projects such as green ports and low emission transport options that utilize renewable energy driven operations to meet global standards of sustainability.

5. Trade Policy Reforms, simplifying customs clearance procedures, reducing bureaucratic inefficiencies, and fostering free trade agreements (FTAs) to attract global shippers and investors.

By leveraging its strategic location, enhancing port efficiency, and integrating advanced logistics solutions, Sri Lanka can position itself as a leading logistics hub in the Indian Ocean region. However, achieving this requires comprehensive policy reforms, investment in state of the arts technology, and a commitment to sustainable logistics practices.

The Eco-Friendly Logistics

Sri Lanka's economic growth depends heavily on its logistics sector, but outdated practices are causing increased greenhouse gas emissions and environmental harm. Globally, transport contributes about 14% of emissions, and logistics adds 3-15% to the carbon footprint of consumer goods (IPCC, 2023; World Economic Forum, 2022). With growing international focus on sustainability and commitments like the Paris Agreement aiming for carbon neutrality by 2050, Sri Lanka's logistics industry must modernize to stay competitive. This requires a major shift to renewable energy, low-carbon transport, smart technologies, and supportive policies. However, challenges such as high costs, old infrastructure, weak regulations, and limited private sector involvement slow progress. Addressing these challenges offers big opportunities for economic growth, better trade, and a smaller environmental impact.

To move towards greener logistics, Sri Lanka should invest in alternative fuels like electric, LNG, hydrogen, and biofuels to cut emissions and improve energy use. Enhancing multimodal transport-such as electric rail, inland waterways, and eco-friendly ports-will also help. Using smart logistics tools like AI for route planning, blockchain for supply chain transparency, and IoT for fleet management can increase efficiency and reduce carbon footprints. Government support through tax breaks, carbon pricing, and green financing is essential to encourage businesses to adopt sustainable practices. By combining new technologies, strong policies, and global sustainability standards, Sri Lanka can become a leading regional logistics hub while meeting climate goals and boosting trade.

Challenges in Adopting Green Logistics

The shift towards green logistics is essential for Sri Lanka to achieve sustainable economic growth while reducing environmental impacts. However, the transition faces numerous challenges, would be encounter critically for huge debt country like Sri Lanka. Additionally, insufficient investment in renewable energy infrastructure slowdown large scale adoption. Here explores these key challenges and examines the steps Sri Lanka must take to overcome barriers and successfully implement green logistics solutions.

1. **Technological Barriers**. Sri Lanka faces major challenges in adopting modern green logistics technologies due to limited renewable energy infrastructure, digitization, and automation. Although the country has abundant solar and wind resources, key ports like Colombo and Hambantota still depend heavily on fossil fuels, increasing emissions and lowering efficiency. Sustainable energy solutions such as solar-powered operations, cold ironing, and battery storage are not yet fully implemented. The slow uptake of electric vehicles in freight is further hindered by inadequate charging infrastructure, high import taxes, and limited subsidies. Meanwhile, regional competitors like Singapore and Dubai are advancing with hydrogen fuel and smart grid

technologies, exposing Sri Lanka's weak green energy ecosystem. Additionally, logistics operations remain largely manual, with underused smart technologies like automated cargo handling, blockchain trade documentation, AI logistics, and IoT fleet monitoring. This results in inefficiencies, higher fuel use, delays, and increased emissions. To address these issues, Sri Lanka should focus on public-private partnerships, regulatory incentives for green tech adoption, and international knowledge sharing. By combining digital innovation, renewable energy, and automation, Sri Lanka can improve its logistics competitiveness and meet climate goals.

2. **Infrastructure Gaps**. Sri Lanka's logistics sector faces major challenges due to outdated facilities and limited capacity to meet growing freight demand. Colombo Port, the main maritime hub, experiences severe congestion from capacity limits, slow digitalization, and inefficient cargo handling, weakening its competitiveness against regional hubs like Singapore and Dubai. Despite its strategic location, the port's potential is underused due to poor hinterland links, lack of integrated services, and underdeveloped industrial zones. The railway network handles less than 2% of cargo, missing a chance to offer a low-carbon alternative to road freight (Sri Lanka Railways, 2023).

Road transport dominates inland freight at about 95%, causing high fuel use, emissions, and logistics costs (Ministry of Transport, 2022). Poor road conditions, limited expressways, and inadequate warehousing-especially in industrial and rural areas-reduce efficiency. The absence of cold storage and multimodal hubs limits support for temperature-sensitive goods like pharmaceuticals and perishables, undermining competitiveness in high-value markets. Addressing these issues requires investing in infrastructure, developing multimodal logistics networks, and adopting smart supply chain solutions to boost efficiency, sustainability, and regional trade competitiveness.

3. **Policy and Regulatory Issues**. Sri Lanka faces significant policy gaps in its transition to green logistics due to a lack of a coherent regulatory framework, weak enforcement, and fragmented administration. Although the government aims for carbon neutrality by 2050, environmental policies suffer from poor implementation, inadequate enforcement of emission standards, limited financial incentives, and the absence of industry-specific sustainability frameworks (Ministry of Environment, 2023). Existing regulations, such as tax deductions for renewable energy, EV subsidies, and incentives for sustainable freight, are often insufficient, inconsistently applied, or lack long-term vision (Sri Lanka Sustainable Energy Authority, 2022). Poor coordination among the Ministry of Transport, Ministry of Environment, and Sri Lanka Ports Authority has resulted in overlapping policies and fragmented efforts, hindering integrated green logistics planning. Unlike countries like Singapore and the Netherlands, which have robust green freight programs, carbon pricing, and strict emissions

standards, Sri Lanka's policies fall short of international best practices, limiting its ability to attract green investments and compete globally. To address these challenges, Sri Lanka must establish a centralized green logistics policy, strengthen enforcement mechanisms, and promote public-private partnerships to invest in sustainable transport infrastructure aligned with global sustainability standards.

4. **Stakeholder Resistance**. Sri Lanka's shift to green logistics is hindered by financial constraints, limited awareness, and risk aversion, especially among small and medium enterprises (SMEs), which make up over 75% of the business sector (Department of Census and Statistics, 2023). SMEs often lack the capital to invest in green technologies like electric freight vehicles, solar-powered hubs, or digital supply chain solutions, as high upfront costs outweigh perceived short-term benefits. Additionally, limited access to green financing, weak government incentives, and unclear return on investment (ROI) models discourage their adoption of sustainable practices (Sri Lanka Sustainable Energy Authority, 2022). Beyond finances, information gaps about long-term economic benefits-such as fuel savings, lower maintenance costs, carbon credits, and enhanced brand reputation-further reduce SME engagement. Unlike large firms driven by global sustainability mandates and ESG compliance, SMEs often lack the technical skills and market incentives to transition to green logistics. To address this, Sri Lanka must implement targeted policies, subsidies, awareness programs, and strategic partnerships that enable SMEs to adopt green logistics in a financially viable manner, ensuring alignment with global trade sustainability standards.

Opportunities in Green Logistics

The green logistics is essential for Sri Lanka to achieve sustainable economic growth and it will enable opportunities to reduce cost while enhancing sustainability. By optimizing transportation, warehousing and many more help to practice eco friendly environment. This chapter unfold the opportunities that can be adopt to Sri Lanka during the way to green logistics

1. **Adoption of Renewable Energy**. Sri Lanka has significant potential to decarbonize its logistics industry by leveraging abundant solar, wind, and hydro power. The government has made progress with mini-hydro plants, large solar farms, and wind projects in Mannar and Puttalam, resulting in renewables contributing 52.6% of the country's electricity (Central Bank of Sri Lanka, 2022). However, scalability remains a challenge due to intermittent energy supply, requiring advanced storage solutions like lithium-ion batteries, pumped hydropower storage, and smart grid integration. The transport sector, which consumes nearly 60% of fossil fuels, needs to transition to biofuels, hydrogen fuel cells, and electric vehicles (EVs). Although Sri Lanka offers incentives

for EV imports and has initiated biofuel pilot projects, adoption is limited by inadequate charging infrastructure, high upfront costs, and unclear policies. Unlike regional leaders such as India and China, which have state-backed EV manufacturing and extensive charging networks, Sri Lanka requires substantial investment in infrastructure, public-private partnerships, and regulatory support to ensure a sustainable and cost-effective green logistics transition. By expanding renewable energy, upgrading grid technologies, and promoting sustainable transport, Sri Lanka can significantly reduce emissions within the global supply chain.

2. **Carbon in Setting Initiatives**. Carbon insetting offers companies a practical way to reduce their environmental impact by investing directly in emission-reduction projects within their supply chains, rather than relying solely on external carbon offsets. DHL's Go Green Plus program exemplifies this approach, enabling companies to offset emissions through reforestation, renewable energy, and sustainable aviation fuels (DHL, 2023). Similarly, Sri Lanka's Carbon Crediting Scheme (SLCCS) provides a national framework for creating and trading carbon credits, encouraging corporate participation in local sustainability projects with tangible emission reductions. For instance, Dilmah Tea uses mini-hydro plants to generate renewable energy, offsetting the carbon footprint of its factories and supporting community energy initiatives. This approach not only advances climate goals but also enhances the global reputation of Sri Lankan businesses amid growing consumer and investor focus on environmental, social, and governance (ESG) criteria. However, broader adoption of carbon insetting in Sri Lanka is limited by low awareness, weak legislation, and insufficient financial incentives for smaller companies. To maximize benefits, Sri Lanka needs to strengthen its carbon market infrastructure, align it with supportive policies, and encourage greater private sector engagement.

3. **Public-Private Partnerships (PPPs)**. Public-private partnerships (PPPs) play a vital role in advancing green logistics by fostering collaboration between government and private sectors to develop sustainable infrastructure and adopt new technologies. PPPs enable pooling of funds, expertise, and innovation to address the high capital costs of projects such as green warehousing, e-documentation, and renewable energy in logistics operations (World Bank, 2023). A prime example is the $392 million South Asia Commercial and Logistics Hub at Colombo Port, which aims to modernize infrastructure with smart port technologies, energy-efficient buildings, and low-emission transport systems (Sri Lanka Ports Authority, 2022). PPPs can also drive investments in renewable energy, electric vehicle infrastructure, and other low-carbon supply chain solutions aligned with Sri Lanka's green growth goals. For PPPs to succeed, clear legal frameworks, long-term policy incentives, and effective risk-sharing between the government and private partners are essential. Strengthening these

partnerships will help Sri Lanka achieve carbon neutrality and establish itself as a regional leader in sustainable trade and logistics.

4. **Digitalization and Smart Systems**. Digitalization has the potential to transform Sri Lanka's logistics industry by boosting productivity, cutting emissions, and enabling sustainable supply chain management. Smart grid energy management systems optimize electricity use, reduce waste, and support the integration of renewable energy like wind and solar in ports, warehouses, and transport hubs (International Energy Agency, 2023). Digitalized port operations using automated cargo handling, blockchain-based e-documentation, and real-time tracking can reduce paperwork, speed up vessel turnaround, and lower fuel consumption by minimizing ship idling (United Nations Conference on Trade and Development, 2022). Adopting a Maritime Single Window system, similar to Singapore's, could further improve Colombo Port's efficiency and pollution control. Accurate carbon footprint measurement tools, such as DHL's Carbon Calculator, are essential for meeting international environmental standards and implementing effective sustainability programs (DHL Sustainability Report, 2023). However, challenges like high implementation costs, outdated IT systems, and a shortage of skilled personnel in data analytics and automation hinder digital transformation. Sri Lanka must invest in digital infrastructure, train logistics professionals, and develop supportive regulations to encourage widespread adoption of smart logistics technologies, thereby building a resilient and sustainable supply chain.

Case Studies

1. **The Initiative to Go Green With DHL**. DHL's Go Green Initiative leads the way in reducing carbon footprints across supply chains, setting a global standard for sustainable logistics. Central to this program is the DHL Carbon Calculator, which helps companies measure and improve their emissions by promoting low-emission transport options (DHL Sustainability Report, 2023). DHL also pioneers the use of Sustainable Aviation Fuel (SAF) in airfreight, significantly cutting Scope 3 emissions, which form a large part of supply chain environmental impacts (International Air Transport Association, 2023). SAF can reduce lifecycle carbon emissions by up to 80%, making it crucial for aviation decarbonization (World Economic Forum, 2023). Alongside international sustainability laws like the EU Emissions Trading System (ETS), DHL's efforts set industry benchmarks, encouraging other logistics firms to adopt green supply chain solutions and carbon insetting policies.

2. **Dilmah Tea's Carbon Neutrality with Renewable Energy Projects**. Dilmah, one of Sri Lanka's largest international companies, has achieved carbon neutrality through innovative renewable energy projects supported by the Sri Lanka Carbon Crediting Scheme (SLCCS). Its investment in mini

hydro plants within tea plantations enables clean energy production, reduces operational emissions, and contributes to national carbon offset efforts (Dilmah Environmental Report, 2022). By lowering its carbon footprint with certified carbon credits, Dilmah has enhanced its brand reputation in global markets where sustainability is increasingly important. Eco-labels and Environmental, Social, and Governance (ESG) compliance are influencing consumer preferences and commercial regulations (Global Reporting Initiative, 2023). Dilmah's approach offers a successful model for other Sri Lankan manufacturers and exporters to adopt low-carbon production, supporting the country's 2050 net-zero goals.

3. **Colombo Port Hosts the South Asia Commercial and Logistics Hub (SACLH)**. A 392 million Doller PPP project, the South Asia Commercial and Logistics Hub (SACLH), seeks to integrate sustainable practices with contemporary logistical capabilities at Colombo Port (Sri Lanka Ports Authority, 2023). This advanced initiative combines energy efficient port operations, digitalized cargo management systems, and shore power facilities (cold ironing) to minimize emissions from ships while at berth and thus is an improved green logistics infrastructure (International Maritime Organization, 2023). Investments in sustainable port management systems are vital to remain competitive against regional players such as Singapore and Dubai, which have already embraced smart logistics solutions, since Colombo Port is one of the busiest transshipment hubs in South Asia (United Nations Conference on Trade and Development, 2023).

Recommendations

To effectively promote green logistics, Sri Lanka must implement a multi faceted policy framework that integrates financial incentives, regulatory reforms, and strategic national planning.

1. **Financial Aid for Green Energy projects**. Promoting renewable energy use in logistics is key to reducing fossil fuel dependence in Sri Lanka. Despite strong solar, wind, and hydro potential, high initial costs and limited government support hinder adoption (Sri Lanka Sustainable Energy Authority, 2023). Capital grants, feed-in tariffs, and low-interest green loans can encourage energy-efficient freight, solar-powered operations, and wind-assisted shipping.

2. **Tax Motivation to Businesses Under ISO 14001**. ISO 14001 certified businesses improve sustainability, resource efficiency, and regulatory compliance. Countries like Japan and Germany offer tax credits and reduced tariffs to encourage certification (International Organization for Standardization, 2022). Sri Lanka could adopt similar measures-fast-track approvals, import duty waivers on eco-friendly logistics equipment, and corporate tax reductions-to boost adoption of international environmental standards.

3. **Strengthening of the Enforcement Mechanism for Environmental Regulations**. Weak enforcement of environmental laws hinders Sri Lanka's goal of carbon neutrality by 2050 (Ministry of Environment, 2023). Poor monitoring, lenient penalties, and opaque carbon reporting reduce compliance. The government must strengthen carbon pricing, mandate emissions reporting for logistics firms, and adopt digital tools like blockchain-based carbon tracking. Enhanced enforcement will align Sri Lanka's logistics sector with global commitments such as the Paris Agreement and IMO decarbonization targets.

4. **National Green Logistics Policy**. A green logistics strategy is essential for sustainability, global standards, and attracting green investments. Countries like Singapore and the Netherlands lead through integrated green freight, multimodal transport, and smart ports (United Nations Economic and Social Commission for Asia and the Pacific, 2023). Sri Lanka can accelerate green logistics by combining PPPs, carbon pricing, EV infrastructure, and renewable energy incentives.

5. **Infrastructure Development**. Modernizing Sri Lanka's infrastructure with green technologies like LNG bunkering, cold ironing, and smart port automation will reduce emissions and optimize energy use (International Maritime Organization, 2023). Developing multimodal logistics hubs will improve freight efficiency and reduce reliance on fuel-intensive road transport. This will boost trade competitiveness, attract green FDI, and strengthen economic resilience.

6. **Stakeholder Collaboration**. Joint training programs by government, private sector, and academia build awareness and skills for green logistics (World Economic Forum, 2023). Stakeholder cooperation is vital to overcome resistance and create sustainable supply chains. Training SMEs in financial literacy and long-term green investments can address challenges in adopting sustainability in Sri Lanka (Sri Lanka Export Development Board, 2023).

7. **Corporate Initiatives**. Corporate leadership is key to advancing green logistics by setting standards and driving innovation. Global firms like DHL use initiatives such as Go Green Plus to reduce emissions through sustainable fuels, renewables, and reforestation (DHL Sustainability Report, 2023). Implementing ISO 14001 boosts resource efficiency, regulatory compliance, and appeals to eco-conscious customers (International Organization for Standardization, 2022).

Conclusion

Sri Lanka's transition to green logistics is essential not only to meet international environmental regulations but also to enhance its long-term sustainability, trade competitiveness, and economic resilience. Leveraging its strategic location as a major Indian Ocean transshipment hub, the country can lead in sustainable logistics by adopting low-emission transport networks, digitalized port operations, and renewable energy solutions such as shore power, smart grids, and Sustainable Aviation Fuel (International Maritime Organization, 2023; United Nations Conference on Trade and Development, 2023). Integrating rail, road, and marine freight into multimodal hubs will improve efficiency, reduce fuel consumption, and promote low-carbon supply chains (International Transport Forum, 2022). Projects like the $392 million South Asia Commercial and Logistics Hub at Colombo Port exemplify successful public-private partnerships that drive sustainability and economic growth.

Corporate initiatives such as DHL's Go Green program and Dilmah Tea's carbon neutrality model demonstrate the feasibility of green business practices in Sri Lanka (DHL Sustainability Report, 2023; Dilmah Sustainability Report, 2022). To fully realize these benefits, Sri Lanka must establish a comprehensive national policy framework that connects sustainability efforts across sectors, strengthens environmental laws, and encourages green investments through tax incentives, carbon credit schemes, and technology subsidies (Ministry of Environment, 2023). Effective inter-ministerial coordination and stakeholder engagement-including public agencies, private companies, academia, and international partners-are critical for success (World Economic Forum, 2023). Capacity-building programs focused on carbon accounting, eco-certifications, and sustainable supply chain management will support SMEs in this green transition (Sri Lanka Export Development Board, 2023). By embracing new technologies, upgrading infrastructure, and implementing supportive policies, Sri Lanka can secure a competitive advantage, contribute meaningfully to global climate goals, and build a resilient, sustainable economic future aligned with growing global emphasis on Environmental, Social, and Governance (ESG) standards.

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A REVIEW ON THE CHALLENGES IN IMPLEMENTING SUSTAINABLE LOGISTICS IN THE SRI LANKAN CONSTRUCTION SECTOR

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Abstract

The construction industry in Sri Lanka presents significant challenges to implementing sustainable logistics practices, which are essential for achieving environmental sustainability and aligning with global Sustainable Development Goals (SDGs). The research is focused on discovering the challenges that prevent people from adopting such approaches. A systematic review of studies was done to assess work related to sustainable logistics in the Sri Lankan construction field. The results highlight some key issues such as shortages in skills, high expenses, restricted access to technologies and low awareness by many people. Because of these obstacles, setting these ideas into practice has proven difficult. It recommends improving schools, training professionals, supporting legislation and promoting advancements in technology to deal with these problems. It calls for companies and organizations from diverse areas to join forces to help achieve a more emissions-friendly and dependable construction scene. The results guide the actions and plans that shape sustainable logistics in Sri Lanka.

Keywords: Sustainable logistics practices, Sri Lankan construction industry, challenges in implementation

Introduction

Economic growth, in turn, helps to promote the world construction industry, as primarily construction fuels, infrastructure, and urbanization. However, on the contrary, significant construction development is responsible for a large share of environmental degradation, hence posing a significant environmental challenge through resource-intensive supply chains, high carbon emissions, heavy greenhouse gas emissions, and substantial construction waste generation (Moganaraj, Zvirgzdiņš and Weerakoon, 2024). Therefore, sustainable logistics have grown to become one of the vital strategies to counteract the effects mentioned negatively. These logistics can reduce carbon emissions in the construction industry while optimizing transportation, procurement of materials, and waste management.

Sustainability construction is heralding a new paradigm shift in the construction industry, moving from the traditional ideas of cost, performance, or quality. It focuses on improving quality of life for humankind in the present and future, while, unlike the traditional way, sustainable construction, would reduce resource deprival and environmental degradation while creating better built environments (Muhammed et al., 2023). The most disadvantageous factor that affects sustainable development on this earth is the contribution of the construction sector to global warming and climate change, as much as it becomes a critical factor in making sustainable practices. Sustainable development is defined by the World Commission on Environment and Development (1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition quickly achieved worldwide acceptance as the basis for the philosophy of sustainable construction (Kumara, 2019). Consolidation of environmental effects with social and economic aspects should lead to construction practices that ultimately realize true sustainability. Thus, the study will inquire into the barriers and challenges to implementing sustainable logistics in Sri Lanka's construction sector.

Research Problem and Objectives

This research investigates the key challenges in adopting sustainable logistics practices within the Sri Lankan construction industry. It aims to identify and categorize the primary barriers based on recent literature from 2018 to 2024, evaluate the interconnections between these challenges, and determine the most impactful factors affecting implementation. Additionally, the study seeks to offer practical insights to guide the industry towards a more sustainable and efficient logistics framework, contributing to both national priorities and global environmental goals.

Methodology

The research methodology employed for a systematic literature review and analysis. This approach was selected to comprehensively identify, evaluate, and synthesize existing scholarly knowledge on the subject.

Literature Review

1. Impact of Construction Industry on the Natural Environment

The worldwide population increase, especially in developing nations, has considerably raised the demand for buildings and infrastructure since 1950. This expansion has threatened to disturb natural habitats over 70% of the earth's surface and creates great pressure on both renewable and non-renewable resources (Kumara, 2019). Buildings have a profound negative impact on the environment, using 30% of global energy and emitting 25% of the total CO2 emissions by 2013. The construction industry produces almost 75% of all global waste, faced by several challenges including environmental issues, material waste, and scarcity of resources affecting productivity. The industry depletes resources and produces greenhouse gases through fossil fuel consumption (Muhammed et al., 2023). Construction activities account for about 35% of global solid waste, emphasizing a need for sustainable building solutions with minimum negative impact on the crucial three Phases: planet, people, and profits (Jayawardana et al., 2023). The adverse environmental impacts of construction require urgent change in operations and management of projects. Previous studies show that there is a need to affect a paradigm shift toward integrating green project delivery techniques to accomplish intended performance outcomes concerning construction projects.

2. Main Challenges in Developing Countries: Sustainable Construction in Sri Lanka

The construction industry is often beset by many obstacles which have somehow affected its sustainable practices similar to what goes on around the globe. Research conducted by Jayawardana et al. (2024) recommends that these barriers should be addressed as they can provide a lot of information that would be beneficial in developing the policies and mitigation strategies aimed at improving the construction efficiency for stakeholders and policymakers. Negative attitudes towards concepts of sustainability are one of the leading barriers. The systemic issues in the construction industry include very poor practices coupled with ineffective collaborations (Gamage et al., 2024). Moganaraj, Zvirgzdiņš, and Weerakoon (2024) noticed that rapid urbanization and infrastructural development across Sri Lanka have accelerated the depletion of resources as well as increased waste accumulation. Traditional construction practices with imperfect legislative control and ineffective waste management infrastructure add environmental impact effects on an already miserable ecological balance of a country and also further slowdown the country's intended pace of progress toward Sustainable Development Goals. Wijesekera (2022) contends that, given the increasing influence of stakeholders over businesses and the escalating competition among them, creating a sustainable business has become more difficult, especially with issues regarding the environment.

3. Sustainable Logistics Methods

Sustainable logistics methods in construction imply the practice of ensuring the most efficient movement, storage, and distribution of material, equipment, and waste with little or no effect on the environment and the greatest possible economic and social benefits. These aforementioned methods were drawn from the referred literature sources as focal methods to reduce the carbon footprint from construction logistics while still ensuring, if not improving operational efficiency, aimed at reducing energy use, greenhouse gas emissions, traffic congestion, noise pollution, and waste creation in construction work, thereby aiding the industry in its move toward sustainable development.

4. Sustainable logistics Frameworks and Concepts

a. Circular Economy

Although the conventional linear economic model (LE) in construction is sustaining a long-term growth trend, it becomes less and less sustainable. Continuous extraction, production, consumption and disposal of resources cause significant strain in ecological systems while jeopardizing long-term resilience (Moganaraj, Zvirgzdiņš & Weerakoon, 2024). The circular economy (CE), on the other hand, advocates for a closed-loop system in resource efficiency, waste-minimization, and regenerative design. It puts material reuse, recycling, and recovery first as regards enhancing resilience, conserving energy, and lowering environmental impact. This is where it departs from the End-of-Life thinking, consistent with continuous material recovery within production, distribution, and consumption (Kulathunga & Kaumudi, 2023). The 3Rs-reduce, reuse, and recycle-ponder upon the pillars of CE strategies forming the extended frameworks incorporating 4R, 6R, and even 10R models to further extend the lifetime of products. The adoption of CE in the construction industry can improve sustainability through waste reduction and optimal use of materials. Industrial Ecology, Biomimicry, Cradle-to-Cradle and Performance Economy are some theoretical frameworks that lend themselves to whole-systems design for implementing CE in construction (Moganaraj et al., 2024). CE principles have been introduced in Sri Lanka from the point of view of improving environmental sustainability during the pre-construction stage of projects (Wijewansha et al., 2021).

b. Green Value Chain (GVC)

Green value creation encompasses the adoption of cleaner production systems and sustainable activities that create value for the organization. Practicing a GVC can substantially lower costs to a business in terms of material procurement, energy use, and waste disposal. As closely related functions, supply chain and value chain management allow green practices to integrate with the overallsustainability. The GVC emphasizes considering innovations in procurement and industrial practices from an environmental perspective while promoting sustainable practices such as recycling, reusing, and substituting materials in its procurement activities (Wijesekera, 2022). The other business functions that are core to the business, such as product-designing, delivering, raw material choice, and waste disposal, are functionally aligned with environmental goals in order to minimize adverse ecological impact.

5. Methods Focused on Resource Efficiency and Reduction

a. Sustainable and Renewable Materials

Presently, the construction industry has the trend of focusing most on environmentally sustainable materials for reducing greenhouse gas emissions and improving their ecological performance (Reddy et al., 2008). Such materials have proven best in various fields, which include packaging, automotive, biomedical, and even engineering uses (Muhammed et al., 2023). But high-rises construction would refer to special conditions, wherein a built facility shall consume a considerable amount of resources and development footprint while transforming society, economy, and environment. Given that fact, the sustainable materials selection becomes necessary in maintaining the sustainability of the high-rises constructed. Hitherto, research studies in Sri Lanka on the material selection frameworks for high-rise buildings remain scant. According to the study conducted by Sachchithananthan & Thayaparan (2024), a validated framework is developed based on 22 sustainable materials pertinent to essential structural elements like walls, floors, partitions, insulation, finishes, doors, and windows. For this particular framework, the materials would then undergo assessments for cost-effectiveness, functionality, performance, strength, local availability, waste management, durability, and energy efficiency. Thus, this specific framework provides a structured approach to material selection toward high-rise sustainability in construction.

b. Off Site Construction (OSC)

Current preference for prefabricated construction (PFC) over conventional construction has been increasingly seen as a viable alternative dealing common industry challenges (Jayawardana and others, 2023). Off-site construction (OSC) over the last decade has gained considerable attention with the publicizing of its potential towards reducing both construction time and cost and enhancing efficiency while being environmentally sustainable. Understanding how developed and developing economies complement each other in promoting environmentally responsible OSC practices is vital, as well as identifying the key success factors for diffuse adoption (Jayawardana et al. 2023b). These are some of the most common advantages associated with PFC: portability, speed of assembly, relatively lower labour intensity, better quality, higher productivity, and substantial environmental benefits.

c. Deconstruction

Demolition activities are responsible for generating over 50% of all construction and demolition wastes, and therefore state and municipal governments are attempting to limit disposal in landfills and incineration.

Entering the scene is deconstruction, which places emphasis on salvaging reusable and recyclable materials and lessening our dependence on virgin resources. This practice will also contribute to decreasing energy consumption, pollution, waste disposal, and global warming effects. Deconstruction entails designing buildings for reuse, adaptation, and renovation of materials to ensure that valuable components are either reused or repurposed rather than discarded. The main objective is to recover as many usable materials as possible, thus preventing them from becoming waste (Kulathunga and Kaumudi, 2023). Deconstruction serves the Circular Economy as an essential component in the construction value chain, acting as a conduit for sustainable resource management and facilitation for development practices.

6. Methods Focused on Optimizing Flows and Processes

a. Reverse Logistics (RL)

In Sri Lanka, reverse logistics (RL) is an essential industrial practice considered important for recovering value from disposed products while reducing waste and pollution (Samarasinhe & Haijun, 2019). As one of the principal processes involved in reverse supply chains, RL makes use of environmentally sustainable practices to emphasize waste management that will, in turn, maximize profitability for the company with equitable environmental disposal options. RL and any reverse supply chain activities engaged in by the company contribute to its being classified as "green." In a broader sense, RL is defined as a systematic approach to planning, implementing, and controlling the movements of raw materials, in-process inventories, and finished goods from the point of consumption to the point of origin economically. The main aim is to either recapture value or ensure proper disposal.

Reverse logistics is essential for redefining a green value chain through remanufacturing, recycling, and material flow. RL conventionally comprises six major processes: accept, take-back, edit, renew, transport, and re-engineer (Wijesekera, 2022). Ultimately, the RL process is concerned with the sustainability of economy and environment alike by reducing manufacturing input through better-quality waste elimination.

b. Sustainable Procurement

Sustainable procurement or green procurement has indeed grown as a well-known remedy in reducing the environmental effects of the construction sector (Kumara, 2019). It involves optimizing resources, best-value procurement, and choosing sustainable materials, products, and services. This also encompasses conventional procurement issues while encouraging Building Information Modeling (BIM). Integrated Project Delivery (IPD), which is

BIM based, is said to be essential for the successful workings of sustainable procurement systems that will develop innovations and sustainability in the construction industry (Rosayuru, Waidyasekara & Wijeweickrama, 2019). Centralized procurement shapes the materials procurement practices of the construction industry today. It is being implemented worldwide but is still underutilized in Sri Lanka. The advantages include lower costs, improved monitoring, and data-derived procurement decisions. (Sivasubramaniam et al. 2024).

7. Methods Leveraging Technology and Innovation

a. Block chain technology

The construction industry can be said to be complex and has highly complicated processes called "Blockchain and smart contracts" (B&SC), which can relatively touch harmonious integration into the constructed facility for smart management and operation (Gamage et al., 2024). Nowadays, the application of Building Information Modelling (BIM) is targeted at existing buildings, which would have been other emerging technologies in use. Some areas of study include analyzing secondary market demand and supply and evaluating cost, safety, and quality within a BIM-enabled environment (Jayasinghe, Chileshe & Rameezdeen, 2019).

Findings

After providing a concise definition and explanation of each method, each of the above methods are reviewed and categorized with how and why these methods are more challenging to be implemented in real-world logistics scenarios while undertaking what hinders the adoption of these methods.

Category	Sustainable logistic method	Key challenges in implementing within SL	How to overcome the said challenges
Frameworks and Concepts	**Circular Economy** (Moganaraj, Zvirgzdiņš and Weerakoon, 2024), (Wijewansha et al., 2021), (Victar and Waidyasekara, 2024)	• Limited knowledge base. • Expertise shortage. • Organizational inertia. • Regulatory gaps. • Technical limitations. • Economic challenges.	• Implement financial stimulus programs for construction companies. • Integrate circular economy principles into engineering education. • Create industry collaboration networks. • Ensure comprehensive stakeholder participation. • Allocate funding for innovation

			research. • Develop and enforce supportive regulations. • Launch educational outreach initiatives. • Promote modular construction and material recycling.
	Green value chain (Wijesekera, 2022)	• Limited environmental consciousness among supply chain partners. • Sources of implementation resistance. • Challenges in evaluating supplier environmental practices. • Value chain stakeholder satisfaction issues.	
Methods Focused on Resource Efficiency and Reduction	**Sustainable and Renewable Materials** (Muhammed et al., 2023), (Sachchithananthan and Thayaparan, 2024)	• Restricted technology access and material availability. • Knowledge gaps and resource limitations. • Need for technological advancement and research. • Insufficient research on Sustainable material selection	
	Offsite Construction (Jayawardana et al., 2024), (Jayawardana et al., 2023b)	• Logistical challenges in component delivery. • Substantial initial investment requirements. • Limited understanding of prefabricated construction benefits among key decision-makers.	• Holistic sustainability evaluation methods. • Advanced technological systems adoption. • Prefabrication efficiency research. • Circular economy and SDG implementation. • Localized research development initiatives.
	Deconstruction (Kulathunga and Kaumudi, 2023)	• Lack of financial funds, technology, machinery, and professionals to execute the concept. • Not designed for disassembly. • Lack of disposal disincentives. • Shorter lifetime of materials.	• Enforce waste disposal regulations. • Organize workshops and awareness programs on deconstruction. • Involve local authorities in implementation. • Integrate deconstruct ability credits in sustainability assessments.

		• Lack of awareness. • Lack of professionals who have the knowledge on material availability, application, their life cycle costing, and specifications,	• Develop advanced dismantling techniques and tools. • Enhance knowledge and skill Development. • Promote technological
		design concepts of replicability and dismantling.	innovations and system improvements. • Expand market opportunities for deconstruction. • Implement regulations, standards, and government Policies.
Methods Focused on Optimizig Flows and Processes	**Reverse Logistics** (Samarasinhe and Haijun, 2019)	• Negative managerial perception of reverse logistics. • Limited resources dedicated to reverse logistics implementation. • Lack of knowledge and expertise in reverse logistics. • Complexity of reverse logistics operations. • Weak commitment from top management. • Financial limitations hindering implementation.	• Owners' responsibility to implement reverse logistics. • Emphasize the significance of RL in the industry. • Educate employees on the benefits and value of RL practices. • Provide guidance on systematic waste recycling and disposal.
	Sustainable Procurement (Sivasubramaniam et al., 2024), (Kumara, 2019)	• Inconsistent procurement practices. • Resistance to change in the construction industry. • Legal and regulatory challenges. • Decline in client satisfaction. • Limited innovation • Reduced stakeholder confidence. • Restricted market competition.	• Establish a legal and regulatory framework for green procurement. • Implement incentive programs to enhance positive perception. • Educate suppliers on green procurement and enforce strict screening & contract management. • Enhance procurement strategies through training and development. • Strengthen communication for a knowledge based green procurement environment. • Prioritize best-value procurement over lowest-price selection. • Integrate financial planning

			with green procurement considerations. • Promote professionalism and stakeholder awareness in green procurement and construction. • Optimize resource utilization and efficiency.
Methods Leveraging Technology and Innovation	**Blockchain Technology** (Gamage et al., 2024)	• Lack of technical expertise • High-cost implications. • Limited blockchain-based applications. • Enterprise reluctance to invest in blockchain integration. • Slow adoption of digital technologies.	• Perform industry-wide digitalization analysis. • Develop a comprehensive digitalization strategy. • Hire skilled IT professionals.

Table 1: Summary of the literature findings
Source: Author

Discussion

Following the identification of the main challenges in implementing sustainable logistics in the construction sector, a systematic analysis was conducted to extract the key challenges based on their frequency of mention in the literature and their significance to the industry. This process allowed for a clearer understanding of the most critical barriers to sustainability adoption.

	Lack of technical expertise	High-cost implications	Limited regulatory support	Technological limitations	Lack of awareness	Insufficient research
Circular Economy	√	√	√	√	√	
Green Value Chain	√				√	
Sustainable and Renewable Materials	√	√		√		√
Offsite Construction	√	√		√	√	
Deconstruction	√	√	√	√	√	
Reverse Logistics	√	√		√	√	
Sustainable Procurement	√		√		√	
Blockchain Technology	√	√		√	√	√

Table 2: Summary of the literature findings
Source: Author

It can be evidently seen from the above analysis that some of these identified challenges are the base of all Sustainable Development Goals implementation. They are lack of technical expertise in the field, high cost implications, technological limitations and lack of awareness within the field and among the public. By identifying and analyzing these challenges, the research provides a foundation for developing targeted strategies to enhance sustainable logistics practices in the construction sector.

Conclusion

It is indeed apparent from the above analysis that some of the key challenges identified are basic to the achievements of Sustainable Development Goals (SDGs) in construction. Such core problems faced include deficit technical skills, high-cost implications, technological limitations, and limited awareness both in the industry and the public as core barriers to adopting sustainable logistics practices. This creates a bottleneck in the transition toward greener and more efficient construction methods, indicating that the measures adopted to solve these problems would have to be at various levels. The research thus gives a basis for developing targeted interventions meant to improve sustainable logistics in the construction sector by identifying and analyzing these challenges. Addressing knowledge gaps through education and capacity-building initiatives can also enhance the technical skills, financial incentives and policy-oriented support, however deployed, would mitigate cost constraints. Investment in technological advancement such as the use of blockchain combined with smart contracts will optimize logistics operations, create transparency, and improve efficiency. Further raise public awareness and awareness in the industry about what sustainable logistics entails in order to spur adoption and support needed regulatory changes.

This will eliminate most of the artificial barriers to innovation and speed up the transition to a more sustainable and resilient construction industry in Sri Lanka, thus bringing this industry in line with global sustainability measures. This study significantly contributes to the construction sector by providing a roadmap for integrating Circular Economy (CE) principles, highly beneficial for enhancing material efficiency, minimizing waste, and increasing resilience. The research will thereby help overcome the major obstacles in the sector concerning sustainable logistics with respect to insights on addressing the discourse that will guide policy intervention, stakeholder engagement, and identification of industry best practices. Some recommendations include awareness campaigns for education and regulatory reforms, as well as increase in funding for research and development (R&D), which are directly aligned with the United Nations SDGs, particularly able to:

1. **SDG 11** (Sustainable Cities and Communities) promoting eco-friendly and resource-efficient construction practices.

2. **SDG 12** (Responsible Consumption and Production) fostering material reuse and waste reduction, and.

3. **SDG 13** (Climate Action) mitigating environmental impacts through green logistics solutions.

Above all, these key measures will be instrumental in speeding up the robust transition of the construction industry towards sustainability. The focused tackling of these primary issues will enable Sri Lanka's construction sector to increase its environmental accountability, improve economic efficiency, and contribute to the overall resilience of the built environment, thereby enriching society as a whole.
Finally, they will be key steps toward fast tracking the transition of the construction industry itself toward sustainability. Systematically addressing these key issues would increase environmental accountability, improve economic efficiency, and add to overall resilience in the business environment for the construction sector in Sri Lanka, as would society benefit from this issue.

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