

## Informatics-Enabled Logistics Service Systems under Freight Rate Volatility: Evidence from Malaysian Manufacturers

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**Abstract.** This research conceptualizes marine logistics as an information-intensive service system to examine the Malaysian manufacturing sector's response to structural freight rate volatility. This study redefines freight rate management as a multifaceted service challenge, including coordination and decision-making assistance, departing from conventional macroeconomic perspectives. The project aims to fill the gap in understanding how using information can help move from just reacting to problems in operations to actively coordinating services. A qualitative exploratory methodology was used, including seven semi-structured interviews with top logistics managers in Peninsular Malaysia. The data analysis used a rigorous thematic methodology (Open, Axial, and Selective coding), ensuring that the empirical findings were consistently congruent with the principles of service science. The findings were corroborated by secondary data analysis reports from UNCTAD and the World Bank to verify analytical validity. The findings indicate that the volatility of freight rates has become an inherent characteristic of the marine service system. The shift from reactive cost management to proactive service management through data represents a substantial enhancement in adaptability. AI-driven forecasting and blockchain-enabled documentation are crucial instruments that improve reliability, comprehensibility, and opportunities for value generation in services. Moreover, sustainability compliance (IMO EEXI/CII) is identified as a means to transform traditional cost centers into unique services. The paper concludes by asserting that competitiveness requires a combination of digital service maturity and sustainability requirements. Informatics-infused service capabilities are not just applications, but also the fundamental components of future-oriented maritime supply chains.

**Keywords:** Freight-rate volatility; Malaysian manufacturing; digital transformation; maritime logistics; sustainability; resilience; Informatics; Logistic service systems

## 1 Introduction

The logistics sector is essential for modern trade, enhancing supply-chain efficiency and national competitiveness while also driving economic growth as an information-intensive service system. Its role has expanded with global interconnected production networks, helping to reduce costs and ensure timely delivery of goods to meet international demand. The field's roots trace back to military logistics in the early 20th century, focusing on the procurement and movement of resources during wartime (Ballou, 2007). In the post-industrial era, the logistics business that was traditionally considered a study of transportation and warehousing has developed into a system of a full-fledged logistics service, which is a key to national competitiveness and global connectivity.

Sea freight continues to dominate the global transport system, handling over 90 percent of world merchandise trade by volume (UNCTAD, 2024). Maritime logistics play a significant part in the export-oriented Malaysian economy, given the strategic advantage of the country's location on vital shipping routes, such as the Straits of Malacca. The prominent ports of Port Klang, Tanjung Pelepas, and Penang Port facilitate the smooth conduct of international trade and the manufacturing industry of the Malaysian economy, which accounts for more than 23% of the GDP and provides employment to more than 20% of the population.

Several factors, including fuel costs, the distance travelled, the type of goods, and the availability of containers, determine freight rates. (Cariou et al., 2025). Freight rate management has moved from a basic procurement problem to a complex problem that also includes service coordination and decision support. This complexity has been further compounded by the unpredictability of freight rates due to various reasons, such as the outbreak of the COVID-19 pandemic, geopolitical risks, and fluctuations in energy prices. The COVID-19 pandemic has underscored how vulnerable the logistics supply chain can be. For example, nationwide lockdowns and port closures have made it very demanding to obtain containers. The Movement Control Order (MCO) in Malaysia has caused ports to close temporarily and caused a shortage of laborers, which has affected Port Klang's operations (Tiwari et al., 2024).

Between 2020 and 2022, global sea-freight rates surged to historic highs. The global container freight index exceeded USD 10,000 per TEU in 2021, compared to pre-pandemic averages of less than USD 1,500 (Zheng & Jiang, 2025). According to the Malaysian National Shippers Council (MNSC), freight rates for Malaysian exporters rose between 100 and 700 percent compared with pre-pandemic levels, forcing manufacturers to absorb unprecedented logistics costs (Prapinit et al., 2024). The Federation of Malaysian Freight Forwarders reported that cargo movements were restricted, containers were stranded at ports, and non-essential goods accumulated in storage, worsening capacity constraints.

While global freight rates have since moderated from their pandemic peaks, the shipping industry continues to experience persistent volatility. As of 2025, new sources of instability — including geopolitical conflicts, energy price fluctuations, and trade realignments — are reshaping maritime commerce. The U.S.–China trade war, which began in 2018 and continues to influence global supply networks, has had profound effects on freight patterns across Asia. Tariff escalation between the world's two largest economies led many multinational manufacturers to relocate production to Southeast Asia, particularly Malaysia, Vietnam, and Thailand, to avoid trade barriers (Luo et al., 2023).

This regional shift in manufacturing has increased container traffic through Malaysian ports but also heightened competition for shipping capacity. The rerouting of trade flows and the establishment of new industrial clusters in Southeast Asia have disrupted established shipping networks and contributed to uneven freight-rate adjustments. Furthermore, the decoupling of U.S. and Chinese supply chains, coupled with nearshoring and reshoring trends in advanced economies has intensified demand volatility for maritime services.

In parallel, ongoing geopolitical tensions, such as the Russia–Ukraine conflict and security risks in the Red Sea, have altered major shipping routes, extended voyage times, and increased insurance costs (Sun et al., 2025). The escalating bunker fuel costs and capacity imbalances are causing instability in the

Malaysian manufacturing industry, which relies on the timely and cost-effective management of logistics to sustain its competitiveness. Manufacturing industries, including the electronics, automotive, rubber, and palm oil derivatives sectors, are currently being challenged by the timeliness and costs associated with freight management. In an attempt to address these issues, the Malaysian manufacturing industry is increasingly embracing digitalization, AI, blockchain, and IoT technologies, driven by the implementation of the Malaysia Digital Economy Blueprint (MyDIGITAL) and the National Transport Policy 2019-2030. Digital freight platforms enable real-time rate tracking, automatic documentation, and improved coordination between carriers and shippers (Kafi et al., 2022). This transformation marks a paradigm shift from traditional, paper-based logistics toward data-driven and transparent maritime operations.

Meanwhile, sustainability imperatives are redefining global maritime logistics. The International Maritime Organization (IMO) introduced the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) to enforce stricter environmental performance standards for shipping. In response, carriers are investing in low-sulphur fuels, liquefied natural gas (LNG) vessels, and energy-efficient technologies (OECD, 2024). These transitions, while environmentally beneficial, have added new cost layers that ultimately affect freight rates and supply-chain decisions.

U.S.-China trade decoupling, geopolitical conflicts, the pandemic-induced restructuring, digitalization, and the sustainability imperative have reshaped the maritime landscape for Malaysia's manufacturers. Freight volatility has become part of the system, and what is required is the development of strategies that involve the use of technological innovations, sustainability, and cooperation with other stakeholders. Although the impact of the COVID-19 pandemic and other crises on freight rate volatility has been the focus of earlier studies, the concept of freight rate volatility as part of the system and the use of informatics in logistics services have not been adequately explored. Hence, this study aims to look deeper than just describing the situation and explore how adaptation works, using the Malaysian manufacturing industry as a key example to develop and illustrate service science theory instead of just describing it. The key objectives are as follows:

- 1 Identify the key drivers and patterns of freight-rate volatility affecting Malaysian manufacturers.
- 2 Explore how informatics-enabled services and platforms help firms improve cost efficiency, forecasting, and logistics management; and
- 3 Assess how sustainability practices and environmental regulations are shaping freight strategies and competitiveness.

Through these objectives, the study contributes to understanding how Malaysia's manufacturing and logistics sectors can enhance resilience amid continued global volatility and digital transformation.

## **2 Literature Review**

### **2.1 Freight-Rate Volatility**

Freight rate volatility, characterized by unpredictable and significant fluctuations in shipping costs, presents a substantial hurdle for global supply chain stability and profitability, especially for export-oriented economies. These fluctuations are often driven by a confluence of geopolitical events, economic shifts, and supply-demand imbalances within the maritime sector, making accurate forecasting and risk mitigation increasingly complex (Wang & Sarkis, 2021). For Malaysian manufacturers, this volatility directly impacts their competitiveness and operational costs, necessitating innovative strategies to manage these unpredictable changes effectively. The digital transformation of the maritime logistics industry, though facing barriers like fragmentation and a lack of transparency, offers pathways to mitigate these challenges through enhanced digital maturity and integrated data analytics (Raza et al., 2022). Such advancements can empower manufacturers to gain better visibility

into market dynamics and optimize their shipping strategies, thereby cushioning the impact of erratic freight rates (Tijan et al., 2021). This emphasis on digital readiness underscores the necessity for Malaysian manufacturers to invest in developing robust change-sensing and seizing capabilities to navigate the complexities of a digitalized maritime economy (Ahmed et al., 2024). This includes fostering an organizational culture that embraces technological integration and allocating sufficient resources for digital infrastructure and skill development (Ahmed et al., 2024). Furthermore, the Malaysian manufacturing sector's readiness for digital transformation is intrinsically linked to its ability to adapt to new technologies and cultivate an employee base proficient in these digital tools (Ahmed et al., 2024). However, a significant gap in skilled personnel within Malaysian manufacturing firms and financial constraints for digital investments often hamper this progression (Ahmed et al., 2024). These challenges necessitate a strategic focus on upskilling the workforce and exploring innovative financing models to bridge the digital divide within the industry (Ahmed et al., 2024).

Moreover, addressing the vulnerability of ICT infrastructure and facilities is paramount for Malaysia to enhance its overall competitiveness in the fintech industry and subsequently bolster digital transformation efforts across all sectors (Glavina et al., 2021). The continuous progress of digital technology has introduced significant transformations within the maritime sector, influencing everything from logistics and navigation to human resource development (Autsadee et al., 2024). This ongoing digital evolution, while offering unprecedented opportunities for efficiency and innovation, also introduces new complexities such as the imperative for robust cybersecurity measures and the need for significant investments in both technology and human capital to overcome resistance to change (So et al., 2023) (Autsadee et al., 2024).

## **2.2 Impact of the COVID-19 Pandemic on Global Freight Rates**

The COVID-19 pandemic significantly amplified pre-existing trends in digitalization and environmental awareness, leading to a greater industry-wide acceptance of digital solutions and data-driven transformations across the maritime ecosystem (Gavalas et al., 2022). This increased appetite for digital adoption has been a crucial factor in driving efficiency gains for shipping firms, demonstrating how data solutions can be leveraged for enhanced operational decision-making (Gavalas et al., 2022). This period underscored the urgent need for robust digital strategies, as businesses worldwide grappled with unprecedented disruptions, highlighting the efficacy of digital tools in maintaining supply chain continuity and adapting to rapid market shifts (Gavalas et al., 2022). The pandemic notably shifted perceptions towards technology in the maritime industry, accelerating the integration of digital platforms and fostering an environment where innovation is more readily embraced (Gavalas et al., 2022). The necessity to maintain business operations amidst travel restrictions, for instance, forced many companies to adopt virtual solutions, thereby accelerating the pace of digitalization in shipping (Raza et al., 2022). This transformation was not limited to operational aspects but also extended to administrative and strategic planning, as firms sought to leverage digital tools for better risk management and resource allocation (Aladwani, 2024) (Gavalas et al., 2022). Consequently, this rapid digital adoption catalyzed by the pandemic has led to a re-evaluation of traditional maritime practices, propelling the industry towards a more technologically integrated and data-centric future (Gavalas et al., 2022). However, this rapid digital embrace also introduces new vulnerabilities, particularly concerning cybersecurity, as the increased reliance on interconnected systems makes global supply chains susceptible to malware, ransomware, and phishing attacks (Haralambides & Gujar, 2023). This rise in cyber threats, particularly phishing, has been exacerbated by the pandemic, with incidents increasing by over 150% per year, as malicious actors exploited the widespread shift to online activities during lockdowns (Hamadouche et al., 2024).

Furthermore, the expanded attack surface due to remote work and increased digitalization has rendered many IT systems, especially older ones, more vulnerable to exploitation (Karaś, 2023). The maritime industry's rapid digitalization, accelerated by the pandemic, has amplified these cyber risks, with the

integration of advanced technologies like 5G and satellite networks creating new avenues for cyberattacks (Kuhn et al., 2021) (Spaniol, 2022). This increased interconnectedness, while offering significant operational benefits, simultaneously necessitates a heightened focus on cyber resilience to protect critical infrastructure and sensitive data (Katsikas et al., 2024).

### **2.3 Geopolitical Realignments: The U.S.–China Trade War and Supply-Chain Reconfiguration**

The strategic realignment of global supply chains, partly driven by the U.S.–China trade war, has further complicated freight rate stability, creating new trade routes and altering demand-supply dynamics in various regions. This geopolitical tension has led to a diversification of manufacturing bases away from China, impacting shipping volumes and port call frequencies in Southeast Asia, including Malaysia (Heikkilä et al., 2022). These geopolitical shifts, coupled with regional security threats and territorial disputes, further intensify the complexity of maritime supply chain operations, demanding sophisticated risk assessment and adaptive logistics strategies from Malaysian manufacturers (Dawar & Bai, 2024). Indeed, geopolitical risks, such as political instability and trade disputes, significantly disrupt maritime supply chains through various mechanisms, including port closures and increased insurance expenses (Dawar & Bai, 2024). These disruptions have extensive implications, leading to amplified costs, reduced reliability, and significant blockages in the supply chain, ultimately affecting international trade flows (Dawar & Bai, 2024). For instance, geopolitical conflicts, such as the war in Ukraine, have profoundly impacted global logistics, particularly within the maritime sector, through sanctions and disruptions to critical shipping lanes (Dawar & Bai, 2024).

Moreover, Malaysia's stringent lockdown measures implemented in response to the COVID-19 pandemic significantly disrupted haulage operations, exacerbating existing supply chain vulnerabilities and impacting port efficiencies (Zhao et al., 2022) (Prapinit et al., 2024). These measures not only constrained the movement of goods but also highlighted the interdependence between land-based logistics and maritime trade, leading to a cascading effect on freight rates and delivery schedules (Prapinit et al., 2024). The intricate web of global commerce, particularly maritime trade, is inherently susceptible to a multitude of interconnected risks, including geopolitical volatility, cybersecurity threats, and the lingering effects of the pandemic (Dawar & Bai, 2024) (Dillon, 2023) (Arowosegbe et al., 2024). This confluence of factors necessitates a nuanced understanding of risk management strategies, particularly for Malaysian manufacturers navigating the complexities of an increasingly digitalized maritime economy (Shah, 2025). Mitigating these multifaceted risks necessitates a comprehensive approach that integrates insurance coverage, diversification of routes, and the establishment of regional distribution centers (Dawar & Bai, 2024).

### **2.4 Port Operations, Container Management, and Supply-Chain Constraints**

Effective port operations and meticulous container management are paramount for mitigating freight rate volatility, as inefficiencies in these areas directly translate to increased costs and delays within the maritime supply chain. These elements are critical for maintaining fluidity and predictability, especially when confronted with unpredictable global events and surges in demand that can quickly overwhelm existing infrastructure. For instance, bottlenecks in container handling, stemming from insufficient equipment or labor shortages, can lead to vessel backlogs and inflate demurrage and detention charges, directly impacting overall shipping costs (Arowosegbe et al., 2024). The lack of integrated digital systems across port authorities and shipping lines further exacerbates these issues, hindering efficient vessel turnaround times and optimal container utilization. Furthermore, the pandemic-induced surge in cargo volume after lockdown measures were lifted created significant port congestion due to vessel bunching and decreased container turnaround times, compounding the operational challenges (Tiwari et al., 2024). This congestion subsequently led to substantial delays and increased shipping costs, further exacerbating the financial burden on manufacturers and logistics providers (Mahdiraji et al., 2024).

Such operational impediments underscore the critical need for advanced port management systems and optimized container logistics to enhance resilience against future disruptions (Arowosegbe et al., 2024). Addressing these challenges effectively requires proactive risk management strategies, such as diversifying suppliers and transportation routes, coupled with technological investments in areas like advanced analytics and automation to optimize logistics and strengthen cybersecurity defenses (Arowosegbe et al., 2024).

Such proactive measures also encompass exploring alternative transportation methods and routes to mitigate the impact of disruptions, including geopolitical instabilities or infrastructure failures (Dawar & Bai, 2024) (Arowosegbe et al., 2024). Furthermore, implementing predictive analytics for freight rates, informed by machine learning models and real-time data, offers a strategic advantage for Malaysian manufacturers in proactively managing costs and optimizing their supply chain decisions (Yin et al., 2024). This approach enables a more informed response to market fluctuations, allowing for more adaptive procurement and distribution strategies.

## **2.5 Digital Transformation and Technological Adaptation**

The rapid adoption of digital technologies is crucial for Malaysian manufacturers to enhance resilience and efficiency within their supply chains, particularly in navigating unpredictable freight rate volatility (Kayıkçı et al., 2024). This digital transformation extends beyond mere automation, encompassing the strategic integration of advanced analytics, artificial intelligence, and blockchain technologies to optimize logistics and improve transparency across the entire shipping ecosystem (Gao et al., 2023). For example, the deployment of distributed ledger technology, intrinsically linked with the Internet of Things and big data, significantly enhances data transparency and demand management, enabling the tracking of millions of containers globally (Tiwari et al., 2024). The application of AI and machine learning, in particular, facilitates complex production scheduling for SMEs, enabling greater responsiveness and adaptability to market changes (Binti Sifiga, n.d.). This integration also extends to the development of dynamic early warning mechanisms that leverage big data, knowledge graphs, and 5G technologies to enhance risk perception and collaboration across the maritime supply chain (Chen et al., 2024). This technological embrace allows for more precise forecasting of freight rates, enabling manufacturers to make informed decisions regarding optimal shipping windows and modes of transport. Moreover, the digitalization of trade finance through platforms like blockchain can streamline transactions, reduce administrative overhead, and mitigate financial risks associated with international shipping. These advancements are particularly vital for Malaysian SMEs, which often face incompatible cost structures and digital infrastructure limitations, underscoring the need for supportive government policies and incentives to foster a digitally skilled workforce and robust technological infrastructure (Chin et al., 2023) (Jusoh et al., 2025). Implementing such digital solutions, including IoT sensors, can enhance supply chain resilience by improving process efficiency, productivity, and inventory management through automated purchasing and traceability (Tian et al., 2023). Digital solutions further enable remote operations, process mechanization, and self-regulated machine performance, potentially reducing the need for on-site staff in manufacturing operations (Tian et al., 2023). This integration of advanced technologies, such as AI, IoT, and blockchain, further facilitates real-time decision-making, enabling proactive responses to supply chain disruptions and optimizing logistics operations for enhanced efficiency (Raman & Selvaraj, 2024).

## **2.6 Sustainability and Environmental Compliance**

Beyond operational efficiencies and technological adaptation, Malaysian manufacturers must also prioritize sustainability and environmental compliance, as these factors increasingly influence global market access and stakeholder perceptions. The growing global emphasis on reducing carbon footprints and adhering to international environmental regulations, such as the International Maritime Organization's decarbonization targets, necessitates a strategic shift towards eco-friendly shipping

practices and sustainable supply chain management. This includes adopting green logistics solutions, optimizing vessel routes to minimize fuel consumption, and investing in cleaner energy sources for maritime transport (Jamaludin, 2020). Furthermore, integrating circular economy principles and leveraging eco-innovations, such as transforming waste into energy fuels, can significantly enhance resource efficiency and reduce greenhouse gas emissions, aligning with global sustainability objectives (Judijanto et al., 2024). This commitment to sustainability also extends to comprehensive waste management strategies and the adoption of advanced technologies for pollution detection and resource allocation, thereby enhancing corporate reputation and stakeholder trust (Judijanto et al., 2024).

Such initiatives not only contribute to environmental preservation but also drive competitive advantages by meeting increasingly stringent regulatory requirements and consumer demand for sustainable products (Judijanto et al., 2024) (Jap, 2024). Moreover, adherence to international sustainability frameworks and certifications, such as those promoted by the Roundtable on Sustainable Palm Oil for relevant industries, can unlock new market opportunities and foster long-term partnerships with environmentally conscious global buyers (Judijanto et al., 2024). This strategic alignment also facilitates access to green financing options and mitigates reputational risks associated with unsustainable practices (Judijanto et al., 2024). The difficulty in complying with such certification schemes, however, often presents a significant challenge for industries, underscoring the need for systematic tools to aid in data gathering and analysis (Jamaludin, 2020).

## **2.7 Manufacturing Competitiveness and Supply-Chain Resilience**

A robust manufacturing sector, underpinned by resilient supply chains, is critical for Malaysia to maintain its competitive edge in the global economy. This requires strategic investments in advanced manufacturing technologies, skill development, and robust infrastructure to enhance productivity and reduce lead times, thereby strengthening its position in international trade networks. This strategic imperative is further compounded by the necessity for a coordinated national energy policy to streamline strategies and support overarching energy transition goals, as disparate ministerial priorities can lead to inefficient planning (Farouk et al., 2025). Addressing these policy inconsistencies through clear regulatory frameworks and incentives is crucial for fostering a stable investment climate, particularly for renewable energy projects (Farouk et al., 2025) (Rani et al., 2025). Economically, the removal of fossil fuel subsidies would further incentivize sustainable investments and accelerate the adoption of renewable energy technologies across the manufacturing sector (Farouk et al., 2025). This transition requires significant investments in renewable energy infrastructure and grid enhancements to meet ambitious energy transition scenarios, ensuring long-term energy security and supporting Malaysia's net-zero carbon emissions target by 2050 (Farouk et al., 2025). This commitment aligns with the National Energy Transition Roadmap, which aims for a 70% renewable energy mix by 2050, albeit with continued reliance on natural gas for baseline generation due to its high capacity factors (Farouk et al., 2025).

However, achieving these ambitious targets will necessitate overcoming substantial challenges, including securing sufficient financial investments, fostering technological advancements, and ensuring public acceptance of new energy infrastructure (Ghosn et al., 2024). The integration of renewable energy sources into the national grid demands significant upgrades to transmission and distribution networks to manage intermittency and ensure reliability (Farouk et al., 2025) (Fernandez et al., 2024). Moreover, significant energy storage solutions, such as advanced battery technologies, will be crucial to support the increasing solar photovoltaic capacities and mitigate grid instability caused by variable renewable energy generation (Farouk et al., 2025) (Fernandez et al., 2024).

## **2.8 Conceptual Synthesis**

As indicated by the reviewed literature, the volatility of freight rates is no longer a cyclical phenomenon but a permanent structural feature of international trade. Although the current body of research

approaches the phenomenon of digitalization as a set of tools, it is necessary to address the lack of attention to the importance of digitalization as a fundamental informatics infrastructure for the support of service delivery and coordination. As indicated by the current body of research, the discussion on maritime logistics is not addressed as a logistics service system, and the management of freight rates is not addressed as a problem of service coordination and decision support. Therefore, it is necessary to address the gap in the understanding of the potential of AI-based forecasting tools, blockchain-based documentation tools, and tracking tools as informatics-based services for the improvement of service reliability and value creation.

This study attempts to address the gap in the understanding of the construction of adaptive capacity in volatile service systems by transcending the limits of the current body of research and exploring the potential of informatics-based infrastructures for the improvement of resilience.

This study contributes to this evolving discourse by analyzing how Malaysian manufacturers navigate freight-rate volatility within a digitalized and sustainability-focused maritime economy. It bridges three critical perspectives: (1) economic and geopolitical drivers of freight volatility; (2) technological and digital adaptation strategies; and (3) sustainability imperatives shaping modern trade.

Collectively, the literature suggests that adaptive capacity — rather than mere efficiency — will determine national and industrial success in the volatile maritime economy of the 2020s and beyond.

### 3 Research Methods

The research method follows a qualitative paradigm, as it is developed to discover better ways of operation and to uncover complex "how-to" adaptation techniques in the logistics industry. The research is specifically developed to be exploratory and theoretical in nature, using the Malaysian industrial environment to enrich theoretical understanding of informatics-enabled logistics service systems. The target respondents were middle and upper management levels of personnel, including executives and managers of the logistics departments of industrial establishments in Peninsular Malaysia. This group of people was selected as the primary unit of analysis because they are the direct decision-makers and are most affected by and aware of the changes in ocean freight pricing as they occur. The seven individuals who were chosen for the interview had different professional backgrounds, such as logistics coordinators, shipping managers, and purchasing directors. Their experiences provided a broad understanding of the complexity of the coordination of services. To abide by the data privacy guidelines and protect the privacy of the data, the names of the organizations and the respondents were replaced by letters (A-G).

Table 1: List of Interviewees

Interviewee	Company	Position
1	A	Logistics Coordinator
2	B	Logistics Department Manager
3	C	Logistics Shipping Manager
4	D	Sales Coordinator and Purchasing Director
5	E	Senior Business Development Executive
6	F	Senior Logistics Officer
7	G	Logistics Department Manager

To determine the accuracy and reliability of the results derived from the qualitative research, the systematic triangulation method was adopted. The different aspects of the research are as follows:

**Primary Qualitative Data:** In-depth interviews were conducted through online meeting platforms to develop a profound understanding of the existing behaviors.

**Secondary Informatics Data:** The results derived from the interviews were compared with published studies on the current digital shipping trends and freight rates published by international organizations such as UNCTAD and the World Bank.

**Convergence Analysis:** For example, the opinions of the managers on the use of real-time tracking and AI forecasting were compared with the results of the surveys published by the OECD and Mordor Intelligence to assess the convergence of the company's experiences with global trends.

To go beyond the level of descriptive reporting and move towards more analytical abstraction, the thematic analysis model, as outlined by Braun and Clarke (2006), was used. The coding process was carried out in three stages, as follows:

1. **Open Coding:** The data was coded on a line-by-line basis, and the initial concepts and meanings related to informatics-enabled services, such as “AI forecasting,” “blockchain documents,” and “shipment tracking,” were obtained.
2. **Axial Coding:** The codes were grouped in clusters, and the analysis of the data was carried out based on meaningful categories. For example, all the codes related to predictive analytics were grouped under the category of "Forecasting and Predictive Planning."
3. **Selective Coding:** The major themes were also obtained by examining the relationship between the informatics capabilities and the concepts in the service system, and the results were ensured to be consistent with the logic of service science.

## **4 Results and Discussion**

The results of seven semi-structured interviews with senior logistics and manufacturing managers show that Malaysian manufacturers are moving from a reactive approach to crisis management to a proactive service orchestration model. This transition is required due to the transformation of freight-rate volatility into an irreversible, structural characteristic of the global marine system. The literature review combines the key findings of the interviews with the secondary data to consider the study objectives.

### **4.1 Causes and Persistence of Freight-Rate Volatility**

Every respondent admitted that, despite the fact that the COVID-19 pandemic caused the first spike in global sea-freight rates, it has since become a structural and long-lasting characteristic of maritime trade. The managers of Companies A, B, and D also explained the ongoing instability due to the fluctuation of energy prices in the world market, political disputes, and the strength of control over the key capacity provided by the large carrier unions. Company B remarked that “*freight no longer depends only on cargo demand—it moves with oil prices and politics.*”

This image coincides with the conclusions made by the Organization for Economic Co-operation and Development (OECD, 2024) and the United Nations Conference on Trade and Development (UNCTAD, 2024), which point to the post-pandemic freight movements as influenced by the inflation of the energy prices, port productivity, and consolidation of carriers. Moreover, the participants emphasized that other wars, like the Russia-Ukraine conflict and the Red Sea disturbances, have contributed to the increase in the distances and insurance costs of some of the Asia-Europe routes by 10-15 days (Dawar & Bai, 2024). This situation has turned freight-rate monitoring from a routine duty into a necessary part of decision-making for service survival. The fact that container imbalances are still happening, moving 25% of worldwide movements, shows that traditional demand-supply logistics aren't working properly and need to be adapted using informatics.

## 4.2 Operational and Strategic Effects on Malaysian Manufacturers

The second significant conclusion is about the operational and financial consequences of unstable freight rates. According to all interviewees, the cost of logistics is still significantly increased in comparison to the pre-pandemic period. Companies E and F projected that the present freight costs to Europe and North America are 2035 per cent more expensive than in 2019, which whittles the profit margin and prompts price negotiations with foreign purchasers. This is in line with The Edge Malaysia (2024), which reported the reduction of exporters' profits by up to 8 percent because of the increased transport expenses.

In Companies A and C, respondents also cited that such vessel schedule interruptions necessitated increasing warehouse capacity and buffer inventories, often to the point that it now operated on *just-in-time rather than just-in-case*. The transition from "just-in-time" (JIT) to "just-in-case" (JIC) represents a fundamental change in the value proposition of service. In response to cost increases of 20–35%, which have reduced profit margins by 8%, companies have increased average inventory ratios by 22%. A similar pattern is reflected in the report on the Asia-Pacific manufacturers by the World Bank (2024). The small-scale manufacturers (Company D and Company G) are subject to a "volatility premium" of 10-15% per route as a result of vessel space priority, which is essential for service coordination, which confirms the data of the Federation of Malaysian Freight Forwarders (2024). Some of the respondents spoke about shifting exports to South Asia and Africa to reduce risk in high-cost corridors, underpinning (Anuar et al., 2025) on the rebalancing of trade across regions. All of these effects allude to the fact that long-term volatility has reconfigured the management of costs, timelines of procurement, and the approaches to entering the market among the manufacturers in Malaysia.

## 4.3 Acceleration of Digital Transformation & Informatics Infrastructure as a Value Enabler

Digitalization is redefined not as a set of instruments but as a form of informatics infrastructure that makes service delivery and coordination easier. AI-based dashboards transform raw data, such as oil indices and capacities, into predictive services in companies A, D, and F. Company A explained that "predictive systems tell us the right time to book containers—this alone saves cost and stress." This approach reduces "service stress" by 40% as organizations attempt to convert data into cost predictability (Mordor Intelligence, 2024).

Company E used blockchain-based documentation, which is a form of a transparency-enhancing mechanism that reduces coordination friction by 60% and accelerates customs clearance from three days to less than 24 hours (Guan et al., 2024). Firms B and C collaborated with online freight forwarders that allow real-time route optimization and tracking of cargo. Nevertheless, reasons given by SMEs include the prohibitive cost of software subscription and the lack of compatibility with old systems. According to the estimates of the Ministry of International Trade and Industry (MITI, 2024), of all the Malaysian logistics SMEs, only 35% are fully digitalized. In spite of these challenges, the respondents unanimously assumed that digitalization has gone beyond the level of an optional improvement to a need to mitigate risks, which makes processes more visible, simplifies decision-making, and makes costs more predictable.

## 4.4 Sustainability and Environmental Adaptation

Environmental regulation and green-logistics practices have also emerged as significant influences on freight costs and competitive strategy. Respondents acknowledged that compliance with the International Maritime Organization's (IMO) Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) since 2023 has led carriers to impose additional surcharges. Company F noted that "*we don't own vessels, but our freight bills now include green compliance fees.*" (OECD, 2024) projected that such sustainability measures could raise maritime transport costs by 5–10% in 2023–2026.

Companies D and E highlighted that sustainability certification like ISO 14001, carbon-reporting standards to penetrate the markets in Europe, which are sensitive to greenhouse gas emissions. Company D reported winning new clients after attaining a green-logistics label. Additionally, Companies B and C, by incorporating energy-efficient warehouses and hybrid trucks, are not only becoming compliant with regulations but also redefining their brand values to be aligned with Malaysia's national agenda on reducing carbon emissions and converting "compliance fees" into "competitive assets." "These practices corroborate findings by Jamaludin (2020) and Judijanto et al. (2024), who describe sustainability as both a regulatory requirement and a strategic driver for operational excellence.

The last theme is about the incorporation of resilience into the logistics systems of firms. Freight contracts with periods of three years and more have turned companies B and D into price stabilizers and an assurance of a container space; according to the Malaysian National Shippers Council (MNSC), the number of such contracts increased by 18% since 2022. Company A has also avoided congestion at Port Klang by diversifying routes at Singapore and Laem Chabang ports, which is in line with (World Bank, 2024) recommendations on multimodal logistics diversification.

Another focus that the respondents emphasized was collective involvement by joining industry associations like MNSC or Federation of Malaysian Freight Forwarders (FMFF) so as to exchange information and push the policy changes. Company C remarked, "*negotiating alone is difficult, but with MNSC, we get collective leverage.*". In addition to collaboration, technological visibility was determined to be the source of resilience. Company F has elaborated that it is now possible to check on each shipment immediately due to digital tracking systems. Visibility and proactive learning as the key components of organizational resilience. The Malaysian manufacturers are therefore moving out of the reactive crisis control to long-term adaptive logistics ecosystems that also incorporate technology, sustainability, and cooperation.

#### **4.5 Recommendations for Malaysian Manufacturers.**

To enable the Malaysian manufacturing sector to compete favorably in the challenging sea transport system, the current study proposes a shift from crisis management to the creation of a flexible system that would promote long-term success. The Malaysian manufacturing sector should emphasize the integration of digital technology into the logistics system, which includes the use of artificial intelligence dashboards for predicting bookings that have risen by more than 40% since 2021 and the use of blockchain technology for reducing the time taken for the process of paperwork by 60%. There is a need to address the gap in the use of digital technology among Malaysian logistics firms, as only 35% of small and medium-sized logistics enterprises in the country are completely digital, creating a need for the government to help mitigate the costs associated with these technologies. The result is not an operational choice but an investment in the information-intensive service infrastructure required to survive freight-rate volatility. Resilience must be built through contractual stability (e.g., 3-year contracts, which have increased by 18%) and collaborative involvement in industry bodies to push for policy changes that favor shippers over carrier unions. This model illustrates adaptive resilience theory, indicating that resilience is fostered as organizations transition from reactive "just-in-time" absorption to proactive contractually stabilized service orchestration. A Malaysian manufacturing firm should thus aim to fully comply with sustainability requirements, such as those of the International Maritime Organization's EEIX and CII conventions, estimated to increase sea haul charges between 5% and 10% until 2026. Attaining green certifications like ISO 14001 and green-logistics labels will be beneficial in reaching emission-sensitive markets and opening more global buyer partnerships. This bridges sustainability to logistics service logic by redefining environmental rules as a differentiating feature in service value. This transitions the discourse from "cost compliance" to "competitive advantage," suggesting that adopting environmentally friendly practices has become an integral aspect of service design. Finally, companies can become more resilient by working together through industry groups like

the Malaysian National Shippers Council and using long-term freight contracts, which have increased by 18% since 2022, to ensure stable prices and capacity.

## 5 Conclusion

This study has illuminated the multifaceted challenges and strategic adaptations undertaken by Malaysian manufacturers in navigating the volatile landscape of freight rates within a rapidly digitalizing maritime economy. Through the conceptualization of maritime logistics as an information-intensive service system, this research affirms that volatility has moved from being a cyclical exception to a permanent feature of the maritime system. The results demonstrate that to be competitive in the 2020s, it is not sufficient to be operationally efficient; it is necessary to be institutionally proactive in terms of service orchestration. The research underscores the critical interplay between digitalization, sustainability, and strategic resilience-building as manufacturers contend with fluctuating global freight markets and evolving regulatory frameworks. Key findings indicate that while digitalization offers significant opportunities for enhanced visibility and operational efficiency, its adoption presents hurdles such as high implementation costs and integration complexities. Despite these challenges, the imperative for digital transformation remains, driven by the potential for greater supply chain resilience and transparency. This is particularly relevant given that digitalization can catalyze improvements in maritime supply chain resilience by supporting other critical preconditions. Indeed, digitalization plays a catalytic role in enhancing resilience, often by enabling better carbon emission control, early warning capabilities, and synergistic coordination among supply chain actors.

Next, future researchers are encouraged to find specific sectors of manufacturing firms, such as pharmaceutical, agriculture, food, and other related manufacturing industries. This is because the SME has limitations on fewer international trade activities per month after getting in touch with the interviewees; thus, their performance may not be deeply affected when they focus more on local trading. SMEs are largely overtaken and at risk of closure due to the rise of multi-corporations. Likewise, the recommendations listed must also be regarded as a guide or point of reference for the manufacturing and logistics-related firms in the market, as the pandemic remains a threat to the world and case rates are still increasing, although lockdown and border restrictions have been eased. In advance, an effective supply chain process would undoubtedly strengthen Malaysia's manufacturing and logistics industry's competitiveness while fostering the nation's economic expansion in the future.

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