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OPTIMIZING EMPTY CONTAINER MOVEMENTS IN MARITIME INDUSTRY: A SIMULATION-BASED APPROACH AMIDST GEOPOLITICAL CHALLENGES

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Review paper

Abstract: *The maritime industry, responsible for over 90% of global trade, faces significant challenges in managing empty containers due to global trade imbalances. The management of these containers has become a critical focus within the industry, with the need for strategic repositioning plans to reduce dwell times and storage costs. The rise of nationalist movements, such as the Houthi rebel group's attacks on commercial ships, has further complicated this issue, disrupting supply chains and increasing transportation costs. This study explores the current barriers and challenges in managing empty container movements and presents methods, models, and applications to address these issues. It also discusses the impact of geopolitical events on the maritime industry and the implications for empty container transport. The research employs a hybrid approach, combining qualitative and quantitative methods, and utilizes advanced mathematical and computational simulation methods to model the return of empty containers to Asia. The results demonstrate the significant impact of different repositioning strategies on container utilization, company profit, and container turnover, highlighting the importance of strategic management in the maritime industry.*

Key words: *Maritime economic, Container repositioning, Optimization*

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1. INTRODUCTION

The maritime industry plays a foundational role in global trade and the international economy, providing a cost-efficient, secure, and environmentally friendly method for transporting large quantities of goods globally (Hoffmann & Kumar, 2013). Over 90% of global trade is conducted via sea routes (UNCTAD, 2019). The industry relies on an extensive network of administrative and technical systems to support decision-making both onboard and ashore (Algelin, 2010). Managing these operations is complex due to the need to coordinate and sequence multiple concurrent and subsequent operations. Containerization, a major technological advancement during the mid-20th century, revolutionized the shipping business by simplifying the shipping process and reducing costs through automation (Liu, 2010). Consequently, the management of container terminal operations has become a critical area of focus within the maritime industry.

1.1. Challenges in Managing Empty Containers

One of the most challenging logistics issues in the shipping sector is managing the movement of empty containers, primarily caused by global trade imbalances. Regions with higher imports than exports accumulate large numbers of empty containers, while areas with more exports than imports face shortages. Even in developed nations with balanced trade, empty containers accumulate due to imbalances in container types. Rodrigue (2020) notes that 56% of a container's life is spent idle at depots, awaiting future demand or relocation to shortage areas. Therefore, once a container is emptied, a repositioning strategy is crucial, and alternative transport routes must be identified. Delays or errors in selecting a repositioning plan can lead to increased dwell times at depots or ports, resulting in higher storage costs and extended waiting times for containerships, ultimately reducing productivity and the ability to meet demand promptly.

1.2. Reverse Logistics and Global Trade Imbalance

Reverse logistics in the maritime industry involves the return of empty containers from one port to another to meet customer demand, as described by Belayachi et al. (2017). To remain competitive, shipping lines and ocean carriers strive to enhance their services by identifying opportunities to balance container flow between ports. However, the global trade imbalance disrupts this flow, with some countries producing more goods while others import more than they export. Shipping lines must often secure enough empty containers for customers in shortage areas, sometimes at significant cost.

1.3. Methods and Models for Managing Empty Container Traffic

To address these challenges, methods, models, and applications for managing empty container traffic can be grouped into three primary perspectives: organizational solutions like container leasing, substitution, and carrier collaboration; technological innovations and new container designs, such as the foldable concept; and modelling techniques that explore different strategies for managing the repositioning of empty containers (Abdelshafie et al., 2022). The ongoing trade imbalance has led many companies to reconsider their strategies for repositioning empty containers, emphasizing the need to maximize profit, container utilization, and customer satisfaction. This study aims to analyse the current barriers and challenges faced by shipping companies in managing empty container movements, which have evolved over time, particularly as increased uncertainty complicates the distribution of empty containers without optimized methods.

1.4. Impact of Houthi Attacks on the Maritime Industry

Since mid-November 2023, the Houthi rebel group, based in Yemen, has been targeting commercial ships in the Red Sea, a crucial maritime route essential for global trade between Europe and Asia. These attacks have caused significant disruptions, leading to a dramatic increase in insurance premiums for ships using the Red Sea, rising from less than 0.1% to between 0.7% and 1.0% of a ship's total value. War risk premiums have also surged, escalating costs for shipping companies (CSIS, 2024; DIA Report, 2024). Many shipping companies are now rerouting their vessels around the Cape of Good Hope to avoid the Red Sea, adding approximately 11,000 nautical miles, 1-2 weeks of transit time, and around $1 million in fuel costs per voyage. This rerouting has disrupted supply chains and increased the prices of goods (How Houthi Attacks in the Red Sea Threaten Global Shipping, 2024). The attacks have caused a 90% decline in container shipping through the Red Sea since December 2023, leading to significant delays and shortages that affect global supply chains and impact industries and consumers worldwide (CSIS, 2024). Humanitarian relief efforts have also been impeded, with delays in aid shipments to countries like Sudan and Yemen and increased costs for aid organizations due to longer routes around Africa (DIA Report, 2024).

1.5. Geopolitical and Economic Consequences

The geopolitical implications are broad, with the Houthis framing their actions as part of a larger struggle against Israel and the United States, potentially drawing international attention and bolstering their legitimacy. Iran’s support adds another layer of complexity and raises concerns about potential wider conflict (CSIS, 2024). In response, the U.S. and UK have increased their military presence in the region to protect shipping lanes, including initiatives like Operation PROSPERITY GUARDIAN. Cargo insurers have adjusted rates to reflect heightened risks, and shipping companies are negotiating new terms to manage increased costs. Some companies are also investing in advanced technologies, such as drones and surveillance equipment, to enhance vessel security and detect potential threats (How Houthi Attacks in the Red Sea Threaten Global Shipping, 2024).

1.6. Implications for Empty Container Transport

The Houthi attacks have had far-reaching effects on global trade, driving up costs, causing delays, and disrupting supply chains. The security and stability of this vital maritime route are crucial for international stakeholders to address. Notably, the impact on the transport of empty containers back to Asia is significant. When ships avoid the Red Sea and navigate around Africa, it increases transportation costs, fuel expenses, and more, including additional costs for transporting empty containers back to Asia (CSIS, 2024).

2. STRATEGIC MANAGEMENT OF EMPTY CONTAINER MOVEMENTS BY SHIPPING LINES

The liner shipping industry represents a unique and vital sector that has garnered substantial attention from both researchers and policymakers. Over the past four decades, the growth of the liner shipping industry has outpaced the overall increase in global trade volumes. The advancement of globalization would have been unattainable without significant progress in this sector, particularly through the container revolution. Despite these advancements, the liner shipping industry remains highly volatile and fraught with risks, characterized by substantial investment costs, fluctuating freight rates, and intense competition (Notteboom & Verhoeven, 2010). Although containerization rapidly transformed the industry, the expansion of liner services was primarily driven by organizational changes within ports, terminals, and hinterlands that capitalized on this new technology. This, in turn, intensified competition among major players in the container market. To maintain competitiveness and attract more business, these players continually seek ways to reduce costs, either through innovation adoption or productivity enhancements. Among the most critical cost-reduction strategies at the operational level is container fleet management, encompassing fleet sizing, container leasing, laden container distribution, and, notably, empty container repositioning. The latter presents a particularly significant challenge due to the global trade imbalance (Braekers, 2013).

The top 10 container shipping lines dominate the market, controlling 90% of the market share and owning the majority of containers. Consequently, they bear the primary responsibility for managing container movements (Song & Dong, 2012). The repositioning of empty containers imposes considerable costs on shipping companies, potentially accounting for up to 27% of total container handling expenses (Stahlbock & Voss, 2010). Therefore, strategic decisions must be meticulously managed to ensure that empty containers are stored and moved efficiently, so they are available at the correct location, time, type, and size. The development of efficient and effective repositioning strategies has significant economic and environmental implications throughout the container transport chain. To fully comprehend the role of shipping lines in mitigating the challenges associated with empty container movements, it is essential to explore their business operations in greater detail.

Shipping lines operate multiple service routes, offering regular weekly services. Each route adheres to a fixed sequence of ports, with a fleet of container vessels performing repeated roundtrips. It is not uncommon for a single port to be visited multiple times during a single roundtrip. Service routes and schedules are typically published several months in advance of actual voyages.

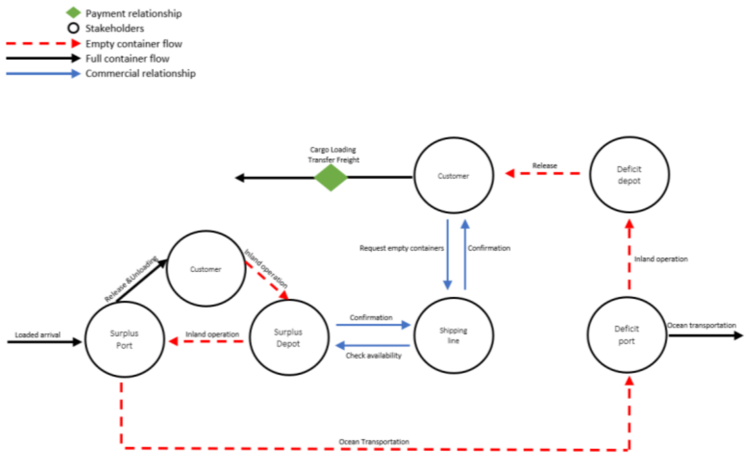

Figure 1. The Logistics Cycle of the Container Transport Chain

Containers represent a substantial investment for shipping lines, encompassing both the forward supply chain of laden containers and the backward supply chain of empty containers. As the owners of these containers, shipping lines are obligated to maximize container turnover and ensure their availability for their intended purposes. Given their proactive role in managing empty containers, shipping lines are best positioned to address mismatches in container location and timing. The profitability of shipping lines is intricately linked to their ability to effectively manage the entire container movement cycle, as containers are transported and stored within the same network, utilizing the same facilities and resources (Heaver, 2002).

This gives rise to the idea of utilizing advanced mathematical and computational simulation methods to model the return of empty containers to Asia. Our goal is to select a strategy that minimally impacts return time while ensuring stable profits for shipping companies. In the long term, this approach could influence stable transportation costs and ensure the smooth operation of supply chains.

3. RESEARCH METHODOLOGY

This study employs a hybrid approach that combines qualitative and quantitative methods to ensure that theoretical and practical insights are derived primarily from literature and participant data. A review of the literature revealed that the research field has been thoroughly explored from various perspectives, including new technology, cooperation, pooling strategies, and vessel routing designs. However, there is a noticeable lack of studies applying Simulation-Based Optimization (SBO) approaches, especially using Netlogo and Simulated Annealing (SA) algorithms.

Netlogo was used to simulate the movement of empty containers and the interactions within this complex system. SA was then successfully applied to find optimal or near-optimal solutions for minimizing repositioning costs. Statistical plots were employed to compare different scenarios for moving empty containers among ports, showing the impact of repositioning strategies on shipping line performance, including total cost, response time, and container utilization.

3.1. Current Practices in Managing Empty Containers

In recent years, a major global shipping line has raised concerns about the increasing costs associated with managing empty containers, prompting calls for more efficient solutions. The management of empty containers within this shipping line is a complex challenge that is closely integrated into the broader supply chain. This process involves coordinating physical movements, negotiating commercial agreements, and fostering collaboration among various maritime stakeholders, including importers, exporters, port authorities, technology vendors, transport companies, and storage facility operators.

The logistics department within the shipping line is responsible for accurately forecasting and managing container stock levels to ensure that the right type of container is available to customers at the right time and place. Given that most trade routes are imbalanced, logistics teams must continuously redistribute different types of containers to meet customer demand. This includes managing the flow of empty containers, determining how many need to be repositioned, and ensuring that they are moved quickly and at the lowest possible cost.

The repositioning process is data-driven, supported by the use of advanced tools like the Geographic Analysis and Information Application (GAIA). This system allows the equipment team to monitor global container stocks, identifying areas of surplus and deficit. As shown in Figure 2, red dots represent deficit regions, while blue dots indicate surplus areas.

To tackle the challenges of empty container management and to reduce the associated costs, the shipping line has implemented several key strategies aimed at improving efficiency and boosting profitability:

- Direct Repositioning: This basic strategy involves reallocating containers from ports with a surplus to ports experiencing shortages. It is typically applied within a specific regional office but can also extend to international movements, where containers are shipped from dominant import markets to dominant export markets.
- Local Repositioning (Cabotage): Similar to direct repositioning, this strategy operates within a single country, moving containers from a surplus port to a deficit port within the same national boundaries.
- Non-Operated Reefer Container (NOR): This strategy involves utilizing reefer containers for dry cargo in regions where there is no demand for reefer services. The containers are

then repositioned to areas with high demand for empty reefer containers, making efficient use of available resources.

- Maintenance and Repair Charges: This strategy leverages contracts with repair terminals, particularly in regions like China. By maintaining damaged containers at special rates in these areas, the shipping line can immediately refill them after repairs, capitalizing on China's status as a major export hub.

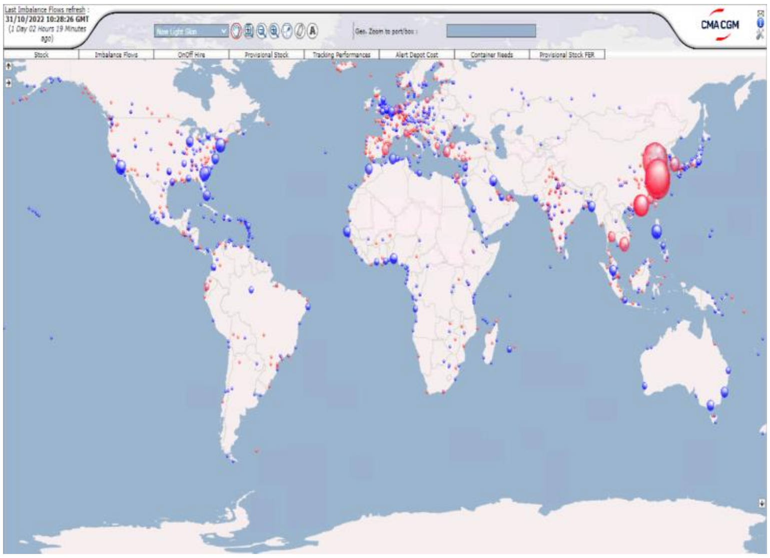

Figure 2. Screenshot of GAIA System

3.2. Analysis and Evaluation of Repositioning Strategies

To assess the effectiveness of these strategies, the shipping line's performance was evaluated using extensive real-life data under two different scenarios. The first scenario involved a random approach, where empty containers were repositioned on a first-come, first-served basis without a specific focus on cost or profit. The second scenario employed an optimized approach, where the shipping line actively sought to maximize profit by considering freight rates and other factors when repositioning empty containers.

The results of this analysis highlighted the significant impact that a well-planned repositioning strategy can have on the overall efficiency of container management. By carefully selecting and implementing appropriate strategies, the shipping line was able to reduce the total costs associated with empty container movements, increase the turnover rate of containers, and improve container utilization rates. This, in turn, contributed to more stable operations and enhanced profitability for the shipping line, while also supporting broader supply chain efficiency.

3.3. Model Implementation and Data Input

Based on the aforementioned, we developed a model and collected data from the Middle East region. The model was tested using real data obtained from the shipping company CMA CGM.

Agent-Based Modeling (ABM) has emerged as an effective approach for tackling complex issues in global maritime logistics (Anand et al., 2016; Christos et al., 2016; Wibowo et al., 2015). ABM enables the design of actors that closely mirror those in real-world logistics systems, allowing for unrestricted interaction between them (Wibowo et al., 2015). This flexibility permits experimentation with various system designs at lower costs, within shorter timeframes, and with reduced risks. In this study, Simulated Annealing (SA) was used to optimize the empty container distribution for shipping line agents, aiming to maximize company profits. The proposed Maritime Empty Container Repositioning Modeling Framework was implemented using the Netlogo simulation platform.

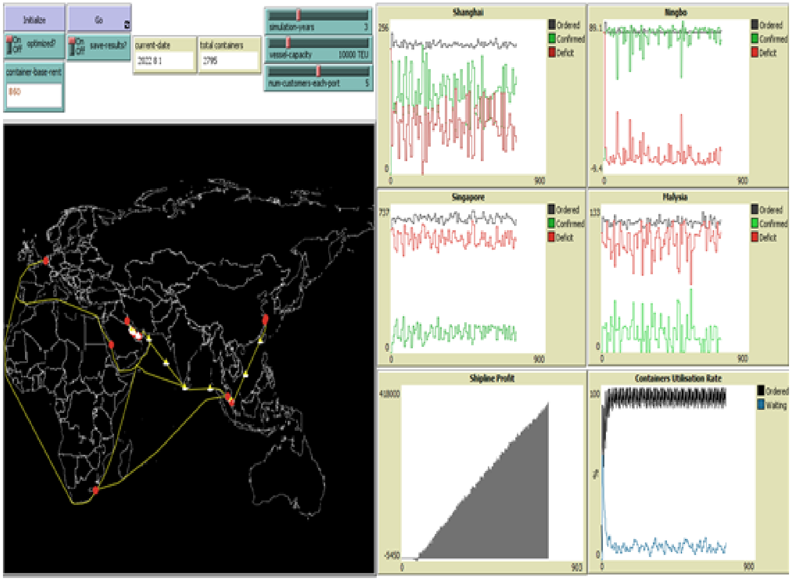

Figure 3. Netlogo Interface for Maritime Empty Container Repositioning Simulation

4. RESULTS AND FINDINGS

The model's results demonstrate the significant impact of different repositioning strategies on container utilization, company profit, and container turnover. Under the random repositioning scenario, profits increased briefly before declining into negative territory for the remainder of the simulation period. Conversely, under the optimized scenario, profits continued to rise steadily throughout the period, as shown in Figure 4. These results suggest that the optimized repositioning strategy effectively reduces costs associated with empty container movements, thereby enhancing company profits.

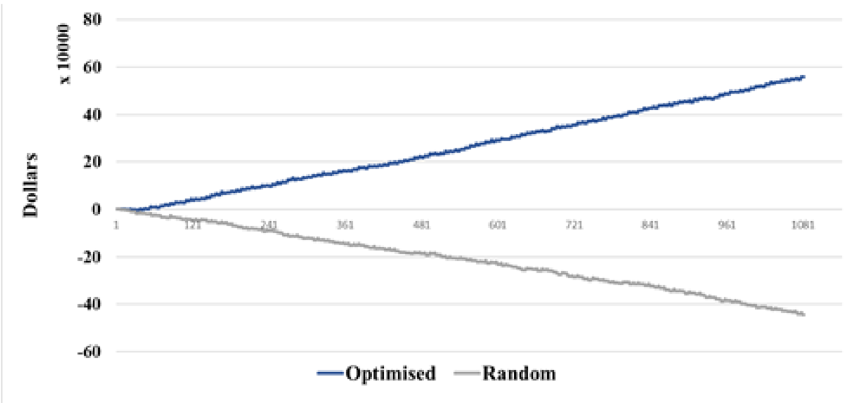

Figure 4. Shipping Line Profit for Empty Containers

When comparing the average turnover days for empty containers between the optimized and random repositioning scenarios, the optimized strategy resulted in an average of 25 turnover days, while the random strategy averaged 20 days. Figure 5 illustrates that the optimized strategy's longer turnover period—five days more than the random strategy—is due to the careful selection of ports based on factors such as distance, demand, and profitability. The random strategy, on the other hand, prioritizes frequent container movements, often to the nearest port or first-demanding port, without considering the potential revenue impact. This approach leads to frequent but less profitable container operations. In contrast, the optimized strategy ensures that empty containers are positioned strategically to maximize their immediate use and secure higher freight rates.

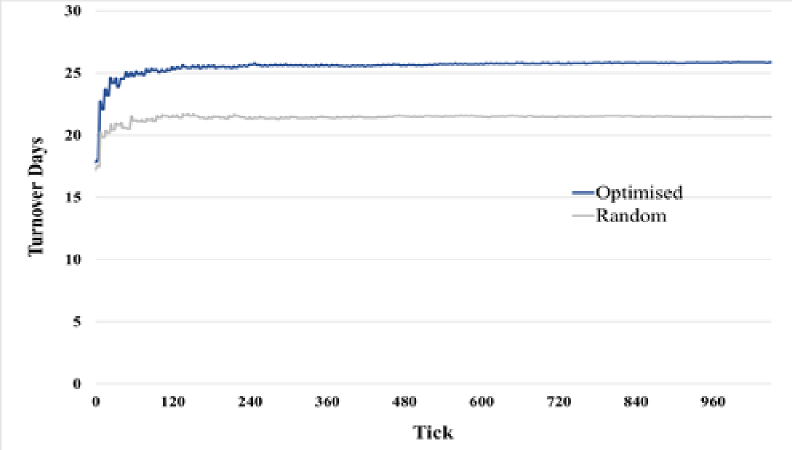

Figure 5. Empty Container Average Turnover Days

The study also evaluated container utilization rates under both scenarios. As shown in Figure 6, the optimized scenario resulted in lower idle rates for empty containers, as they were rapidly shipped to profitable customers, thereby reducing non-revenue-generating periods and additional costs like storage fees. While the difference in idle rates between the scenarios may appear marginal, even small improvements can lead to significant cost savings, particularly given the rising costs of container storage. Enhanced container utilization not only reduces costs but also extends the lifespan of containers, contributing to more efficient asset management.

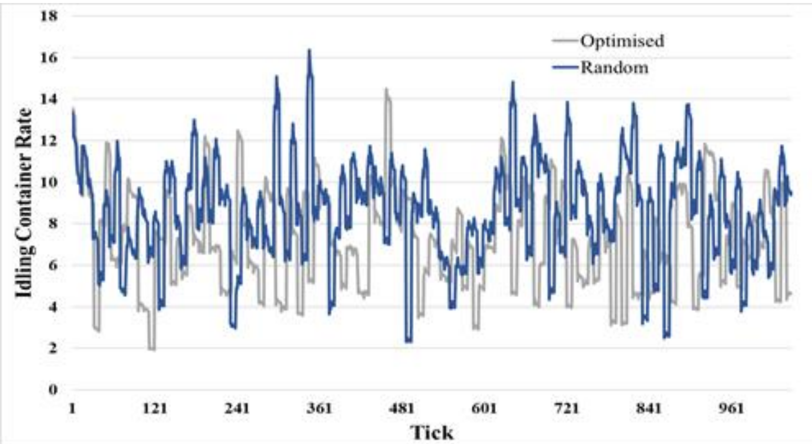

Figure 6. Empty Container Utilization Rate

5. DISCUSSION AND PRACTICAL IMPLICATIONS

Extensive computational tests, including sensitivity analysis, confirm that the optimization simulation approach is both practical and effective. The findings of this study can be summarized as follows:

- Profitability: There is a clear positive relationship between the proposed repositioning strategy and company profit. The optimized strategy successfully generates profitable transport networks by strategically repositioning empty containers.
- Response Time: While the response time for supplying empty containers may increase slightly under the optimized strategy, this delay is outweighed by the overall profitability of the approach. Containers are repositioned based on profitability, location, and demand, ensuring a more efficient use of resources.
- Container Utilization: The optimized strategy enhances container utilization rates throughout their lifespan. This is critical for asset management, as it reduces idle times, minimizes storage costs, and extends the useful life of containers.

The results underscore the importance of adopting sophisticated repositioning strategies in the shipping industry to enhance profitability, improve resource allocation, and ensure sustainable operations.

6. CONCLUSION

This study presents a novel approach to managing the movement of empty containers within maritime logistics by combining mathematical programming with agent-based modelling techniques. By integrating these methodologies, the research offers a robust model that effectively addresses the challenges of empty container repositioning. The hybrid model not only leverages the strengths of both techniques but also demonstrates significant improvements in operational efficiency and profitability.

The findings of the simulation clearly indicate that an optimized repositioning strategy considerably enhances the profitability of empty container management. In contrast, traditional methods, such as first-come, first-served allocation or random assignment to ports with high demand, are shown to lead to financial losses for shipping companies.

Overall, the study underscores the importance of adopting advanced optimization techniques in maritime logistics to improve the management of empty containers. The results suggest that shipping companies can achieve substantial gains in both profitability and operational efficiency by moving away from conventional random allocation methods and embracing more strategic, data-driven approaches.

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