SIMULATION-OPTIMIZATION MODEL IN MANAGING THE EMPTY CONTAINER MOVEMENTS PROBLEM THROUGH REPOSITIONING STRATEGIES

Tomaz Kramberger [(1)i] and Alaa Abdelshafie[(2)]

(1) Faculty of Logistics, University of Maribor, Celje, Slovenia, tomaz.kramberger@um.si

(2) College of International Transport and Logistics, Araba Academy for Science, Technology and Maritim Transport, Alexandria, Egypt, alaa.gaber.mahmoud@aast.edu

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1. ABSTRACT:

In recent decades, the management of container transportation has emerged as a crucial facet of the global maritime industry. The continuous surge in container movement worldwide, driven by economic growth, has inevitably led to challenges related to trade imbalances and empty containers. The logistics associated with empty container movements represent one of the most intricate challenges in the shipping sector. With the escalating global trade imbalances, the imperative repositioning of containers immediately after being emptied has become apparent. This paper delves into the diverse practices governing the motion of empty containers, encompassing organizational policies, technical solutions, and optimization applications. Leveraging the advancements in computer-aided systems, the paper advocates the integration of simulation and optimization models to address the complexities of empty container challenges. It demonstrates how the synergies of optimization-based simulation may yield high-quality solutions at a reduced computational cost. The model's practical application, focusing on ports in Asia and the Middle East, offers insights into its effectiveness for one of the largest shipping lines globally. The results demonstrate that the proposed optimized repositioning strategy can significantly reduce the shipping line's costs and make full use of empty containers in the planning horizon.

2. INTRODUCTION

The maritime industry is acknowledged as the fundamental pillar of the international economy and global trade. It is hailed as the most economical, secure, and environmentally friendly means to transport large quantities of goods (Hoffmann & Kumar, 2013) worldwide. As a result, over 90% of global trade is conducted via sea routes (UNCTAD, 2019). This sector encompasses a significant array of technical and administrative systems aimed at facilitating decision-making both on board and ashore (Algelin, 2010). Coordinating and prioritizing concurrent and post-process operations poses a substantial challenge in managing the ways in which a shipping system operates. Containerization emerged as a pivotal technological advancement in the maritime industry during the mid-20th century, playing a crucial role in streamlining shipping operations. It substantially mitigated the complexities of shipping processes, reducing transportation costs through highly automated goods handling (Liu, 2010). Additionally, the management of container port operations became a major area of concentration in the maritime industry.

Effectively controlling the motion of empty containers presents one of the most intricate logistics challenges in the shipping domain. The world trade imbalance is a primary driver of the accumulation of empty containers in certain regions. Regions with lower exports than imports experience a significant surplus of empty containers, while those with more exports than imports face a shortage. Even in well-balanced trade scenarios in developed countries, the accumulation of empty containers occurs due to imbalances in container types. Rodrigue (2020) asserts that 56% of a container's life is spent idly stacked at depots, either awaiting future demand or placement in areas facing shortages. Consequently, devising a repositioning strategy becomes essential once a container becomes empty, necessitating the identification of alternative transport routes. Any miscalculation or error in choosing the repositioning strategy results in increased dwell time at empty depots or ports, consequently raising storage costs due to extended waiting times for containerships. The prolonged stay of containers not only diminishes productivity but also diminishes the likelihood of timely demand fulfilment.

Within the maritime industry, Belayachi et al. (2017) elucidate the chain of reverse logistics as the transfer of empty containers back and forth between ports to meet customer demand. To stay competitive, various ocean carriers and shipping lines strive to enhance their services by identifying opportunities to balance the number of containers transported in both forward and return directions between ports. Unfortunately, the global imbalance in international trade disrupts the container flow through maritime transportation, resulting in disparities as certain areas produce more than others, and some import more than they export. In such scenarios, shipping lines attempt to secure a sufficient stock of empty containers for customers in shortage areas, often in an ad hoc manner that may entail high costs.

All prevalent models, methods, and applications for addressing the traffic problem of empty containers can be categorized into three perspectives: the first focuses on organizational solutions implemented by shipping lines to reduce empty container movements, such as substitution, container leasing, and collaboration among carriers. The second perspective investigates how novel container designs, such as foldable ideas, and technological advancements can solve the problem of empty containers. The third perspective involves modelling techniques that study various methods for managing the repositioning of empty containers (Abdelshafie et al., 2022).

Due to the ongoing trade imbalance in the shipping industry, most shipping lines have been forced to reevaluate their repositioning strategy for empty container movements, emphasizing the need to maximize profits, container utilization, and customer satisfaction. This research attempts to examine the existing barriers and obstacles faced by shipping companies in the movement of empty containers. These challenges evolve over time, and despite increased uncertainty, distributing empty containers without an optimized method has become exceedingly difficult.

Subsequently, this paper provides an original contribution to knowledge by applying simulation-based optimization to the empty container repositioning problem. The paper will develop a new model by using the Netlogo platform with the SA algorithm, which will be the first to undertake such a combination of tools. It draws attention to the importance of integration and collaboration between maritime sector problems and modelling approaces, especially the new platforms that have not been used yet to solve complex issues showing their influence on the company performance level.

3. RESEARCH METHODOLOGY

The methodology employed in this paper integrates qualitative and quantitative methods to make sure that both theoretical and practical approaches are primarily derived from data extracted from literature and participants. Upon reviewing the existing literature, it was observed that the research field had already been quite comprehensively explored from various perspectives, such as new innovation, cooperation, pooling strategies, and routing designs. However, there is a notable dearth of studies that utilize Simulation-Based Optimization approaches, particularly involving the use of NetLogo and Simulated Annealing algorithms.

Netlogo was utilized to simulate the movements of empty containers and the interactions within the complex system. Subsequently, Simulated Annealing (SA) was successfully employed to identify optimal or near-optimal solutions for decreasing the repositioning costs. Statistical plots were generated to compare different scenarios of transporting empty containers among ports, illustrating the impact of implementing a repositioning plan on the performance of the shipping line. Based on the analysis of in-depth interviews, the relevant data and reports were prepared and became available for building the proposed model. The dataset was checked for missing data and outliers. The obtained data, information, views, and reports extracted from the company will be used to develop a new scientific finding through a Simulation-Based Optimization (SBO) approach. The gathered data were thoroughly analyzed and coded using the 'NetLogo 6.2.2' platform. The simulation model describes the behaviours, characteristics and relationships of real-world problems based on an abstract or mathematical model. This assessment includes considerations of total cost, response time, and container utilization.

4. THE ROLE OF THE SHIPPING LINE IN THE CYCLE OF EMPTY CONTAINER MOVEMENT

The liner shipping industry stands out as a distinctive and peculiar sector, drawing considerable attention from academics and decision-makers. Over the past 40 years, the growth of the liner shipping industry has outpaced that of world trade volumes, playing a pivotal role in the facilitation of globalization, particularly through the container revolution (Notteboom & Verhoeven, 2010). This industry is marked by its inherent risks and volatility, characterized by substantial investments, unstable freight rates, and intense competition (Notteboom & Verhoeven, 2010). The container revolution in 1956 spurred rapid growth in the liner shipping industry, not solely due to the innovation itself but also because of organizational changes in ports, terminals, and hinterlands that leveraged this technological advancement (Notteboom, 2006). The ensuing competition among key players in the container market has led to a focus on cost-cutting strategies, with a significant emphasis on container fleet management, including container leasing, laden container distribution, fleet sizing, and the particularly challenging problem of empty container repositioning (Braekers, 2013).

The top ten container shipping lines, collectively holding a 90% market share, bear the primary responsibility for container movements (Fancello, 2022). These shipping companies grapple with substantial repositioning costs, corresponding to a maximum of 27% of container handling expenses (Stahlbock & Voss, 2010). To optimize their decisions and manage the storage and movements of empty containers effectively, shipping lines must ensure containers are available at the appropriate time, location, size, and type (Song & Dong, 2012). Implementing an efficient and effective repositioning strategy carries economic and environmental implications throughout the container transport chain (Braekers, 2013).

Understanding the role of shipping lines in solving the empty container issue requires delving into their business operations. These companies operate multiple shipping service routes, each with a fixed sequence of ports, deploying a fleet of container vessels to make regular roundtrips. Ports may be called multiple times in a single roundtrip, and schedules are published several months in advance (Braekers, 2013).

Containers constitute the principal investment for shipping lines, whether in the forward supply chain of laden containers or the backward supply chain of empty containers. The ownership of containers obliges shipping lines to expedite the turnaround of containers, ensuring they are swiftly available for the intended purpose. Consequently, shipping lines are proactive players in empty container management, positioned to address issues of container location and timing mismatch, as their profitability is intricately tied to managing the entire cycle of container movements within the same network, utilizing the same resources and facilities (Heaver, 2002).

Figure 1 visually underscores the significance of shipping lines in managing the entire container transport cycle. The process begins with the delivery of full containers to surplus ports, where customers unload cargo and return containers to empty depots awaiting future demand. Upon return, empty containers undergo visual inspection, followed by repair, maintenance, or cleaning operations at the depot before releasing to new customers. When customers in deficit areas request empty containers, shipping lines check their stock and order the required number from surplus depots. These containers are then transported to deficit areas by vessel, with the shipping line releasing containers based on customer bookings. The containers move to their destinations via trucks or other inland transportation methods, and customers pay the agreed freight to the shipping line.

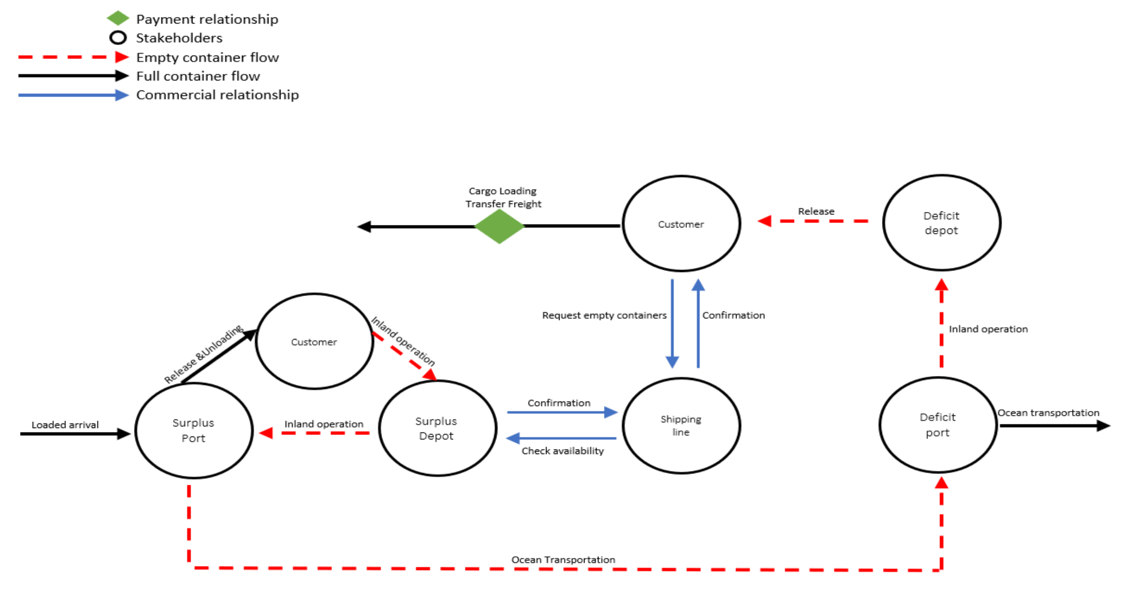

Figure 1. The Logistics Cycle of the Container Transport Chain

4.1 Selection of the case

The studied area focuses on the issue of moving empty containers through a repositioning plan from the perspective of a single shipping line, simplifying the difficulty of the issue. The chosen shipping line for this comprehensive and empirically focused investigation is CMA-CGM, which has grown since its establishment in 1978 to become the third-largest container shipping company in the world. This selection aims to provide an in-depth understanding of various interrelated aspects and complexities of empty container movements and estimate the associated benefits for the company (CMA-CGM, n.d.).

The criteria for selecting CMA-CGM as the case study were based on several elements:

- The shipping line has a strong focus on containerization and a commendable track record.

- The company's involvement with surplus and deficit ports demonstrates an unbalanced direction of container movement.
- The company emphasizes the proper use of resources by playing an active role in sustainable development.
- The shipping line's capturing of not only numerical information on repositioning strategies but also the reasons behind their application and their integration with other strategies.

Shipping companies and maritime ports have a symbiotic relationship, with ports vying to invest significantly in new infrastructure to attract a larger share of container traffic from various shipping lines (Nebot et al., 2017). Ports play a crucial role in economic growth and social development, serving as vital nodes in global supply chains. Infrastructure development and the efficient operation of container ports are often prerequisites for the accomplishment of shipping line expansion growth plans, contributing substantially to overall international trade costs.

To simplify the simulation-optimization model, the research chose ten container ports across several countries, as shipping lines operate on fixed schedules with fixed port turnaround times. The chosen ports exhibit a consistent imbalance in cargo flows over the years, categorized into deficit and surplus ports.

The first category comprises deficit ports, including Dammam (hub port), Singapore, Shanghai, Ningbo, and Port Klang. These ports experience a shortage of empty containers, particularly in the Far East, due to the high demand for empty containers throughout Asia. Singapore, Shanghai, and Ningbo are among the top three ports in terms of container traffic volume in 2021 (UNCTAD, 2021), making the shortage of empty containers more pronounced. Port Klang was selected as the largest deficit port in Malaysia (Komaromi et al., 2022).

The second category consists of surplus ports inside the Gulf region, including Jeddah, Bahrain, Qatar, Umm Qasr, and Jebel Ali. These ports face challenges in filling empty containers for export, leading to congestion and a lack of sufficient resources in the appropriate direction. Jeddah was chosen to understand the local repositioning process within Saudi Arabia, and Jebel Ali was selected due to its status as a sizable commercial port in the United Arab Emirates that ranks among the busiest in the region (Kalim & Syed, 2020). Additionally, Umm Qasr, Salman, and Hamad's ports were chosen as they are the largest ports in their respective countries (Desher, 2019; Rutter et al., 2018).

Table 1. Selected deficit and surplus ports for the model

Port Name	Port Type	Country	Abbreviation	Port Name	Port Type	Country	Abbreviation
Shanghai	Deficit	China	CNSHA	**Jebel Ali**	Surplus	United Arab Emirates	AEJEA
Singapore	Deficit	Singapore	SGSIN	**Umm Qasr**	surplus	Iraq	IQUQR
Port Klang	Deficit	Malaysia	MYPKG	**Khalifa Bin Salman**	Surplus	Bahrain	BHKBS
Ningbo	Deficit	China	CNNGB	**Port of Hamad**	Surplus	Qatar	QAHMD
Dammam	Deficit	Saudi Arabia	SADMM	**Jeddah**	Surplus	Saudi Arabia	SAJED

4.2 The actual practices of managing empty containers in CMA-CGM

In recent years, CMA CGM has expressed concerns about the escalating costs associated with managing empty containers and has called for intervention. Handling empty container management within the shipping line mirrors the complexity of other tasks in supply chains, involving physical movements, commercial agreements, and collaboration among various stakeholders in the maritime sector, such as port authorities, transport companies, technology vendors, storage facility operators, importers, and exporters (Osama et al., 2023).

The logistics task in CMA-CGM related to empty container management falls under the purview of forecasting and stock-level management. The primary objective of the logistics department is to ensure the availability of the correct type of container for customers at the specified time and location of their orders. Given the inherent imbalance in most trades, logistics employees are responsible for redistributing various kinds of containers to fulfil customer needs. Additionally, they oversee the flow of empty containers, determining the specific number of empties requiring repositioning for swift delivery to customers at the lowest cost. The repositioning operations involve the equipment team checking container stocks using GAIA (Geographical Analysis and Information Application). As depicted in Figure 2, GAIA is utilized to identify surplus and deficit areas around the world, with red dots indicating deficit areas and blue dots signifying surplus regions.

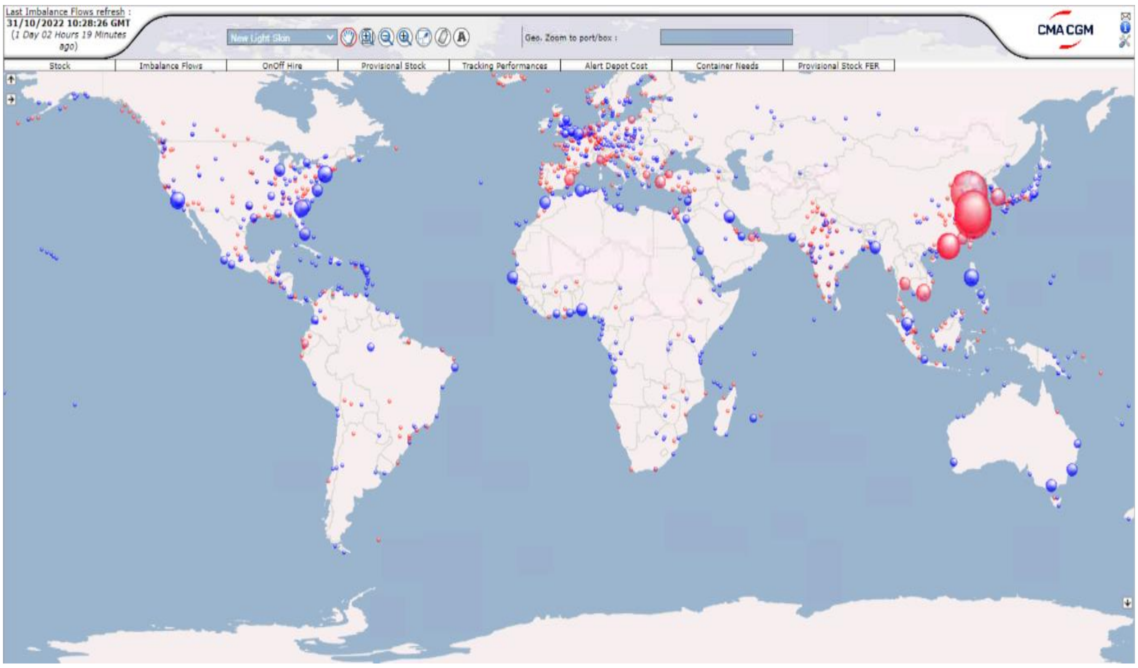

Figure 2. GAIA system in CMA-CGM

Therefore, CMA CGM is undertaking various initiatives to address current challenges by implementing more efficient strategies to reduce empty container movements while simultaneously pursuing economies of scale to enhance their profitability.

1. Direct Repositioning:

- Definition: This basic repositioning strategy involves a port with an excess of containers, beyond its commercial needs, designating some empties to other ports facing a shortage.
- Applicability: This strategy can be implemented between ports under the same regional office, such as those in the Gulf Area. Additionally, unused containers not required for regional imbalances should be shipped globally, addressing deficits in dominant export markets like Asia from surplus markets such as Europe.

2. Local Repositioning (CAPOTAGE):

Definition: Similar to the direct repositioning strategy, this approach occurs exclusively between two ports within the same country, moving empties from surplus ports to deficit ports.

3. Non-operated Reefer-Container (NOR):

Definition: A two-faced repositioning strategy involving loading reefer containers with clean dry cargo at a lower freight rate. This strategy is employed in locations lacking reefer cargo demand, with the final destination chosen based on high demand for empty reefer containers.

4. Maintenance and Repairing Charges:

Definition: This strategy, which can be considered a repositioning technique, involves the shipping company that has an agreement with the Chinese repairing area to maintain damaged containers at a reasonable price. Taking advantage of China's status as the world's largest exporter, the shipping line ensures profitability by promptly refilling the container after repair.

These strategies collectively represent CMA CGM's proactive efforts to optimize its container management practices and enhance overall operational efficiency (CMA-CGM, n.d.).

5. RESEARCH HYPOTHESES

Aligned with the delineation of the problem, research questions, and study objectives, the researcher endeavours to compile pertinent information contributing to the formulation of hypotheses:

Hypothesis 1: The optimal repositioning strategy can lower the overall costs associated with moving empty containers.

Hypothesis 2: The right repositioning plan impacts the turnover rate of empty containers.

Hypothesis 3: The appropriate repositioning approach can increase the container utilization rate.

To ensure the validity of the outcomes, all hypotheses are subjected to testing using the proposed model, employing extensive real-life datasets from the CMA-CGM shipping line. The aim is to ascertain whether each hypothesis is to be accepted or rejected.

To evaluate the company's performance, the study introduces two distinct scenarios: an optimization scenario and a random repositioning scenario. In the random scenario, the shipping line company fulfils customers' empty container requests randomly, employing a first-come-first-serve process without considering costs or profits. Conversely, in the optimization scenario, the shipping line company actively seeks to optimize orders, taking both profit and freight rates into careful consideration.

6. MODEL IMPLEMENTATION AND DATA INPUT

In the development of an optimization-simulation model, Agent-Based Modelling (ABM) emerges as a suitable approach for addressing global maritime logistics issues, as acknowledged by Anand et al. (2016), Christos et al. (2016), and Wibowo et al. (2015). ABM allows for the design of actors mirroring the real logistics system without constraints on actor interactions, facilitating experimentation with various designs for the empty container problem at a lower cost, within a short period, and with reduced risk (Wibowo et al., 2015). Consequently, the study employs the Simulated Annealing (SA) method for shipping line agents to optimize the distribution of empty containers and maximize company profit. Furthermore, the proposed Maritime Empty Container Reposition Modelling Framework is implemented using the Netlogo simulation platform.

The interface of the built model is depicted in Figure 3, where yellow lines symbolize maritime routes, and red dots represent ports. The white ship icons depict vessels. Upon initiation of the model, loaded containers move towards destination ports, disappearing upon arrival and being excluded from the simulation. Simultaneously, empty containers commence movement from surplus ports to deficit ports through shipping routes, aiming to balance container movement and reduce the duration of containers remaining empty.

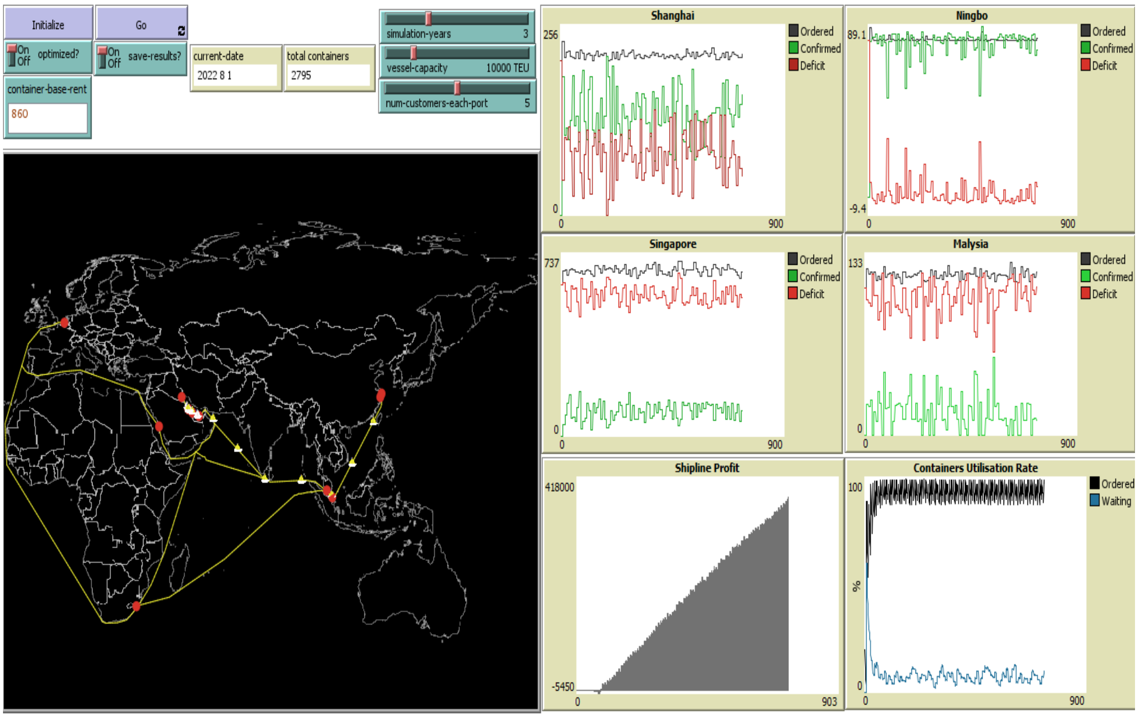

Figure 3. NetLogo Interface for Maritime Empty Container Repositioning Simulation

7. RESULTS AND FINDING

The results of the model are being outlined to measure the effect of the repositioning model on container utilization, company profit and container turnover. As shown in Figure 4, the model results show that the random repositioning scenario's profit margin climbs briefly to positive before going negative during the rest interval. Additionally, throughout the simulation time, the optimized repositioning scenario's profits climbed consistently. These findings make it abundantly evident that the company's profit was positively impacted by the optimized repositioning strategy, as well as the related expenditures. It suggests that the decision to relocate empty containers needs to be supported by an adequate repositioning model.

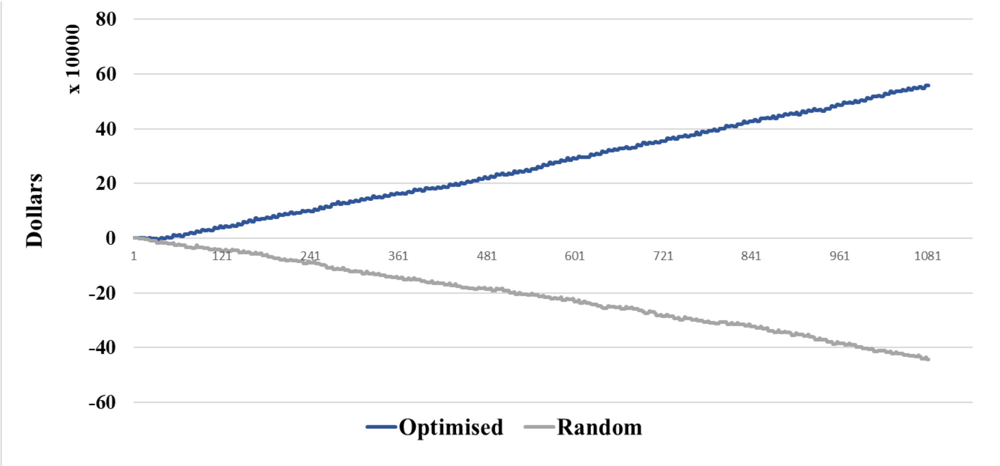

Figure 4. Shipping line Profit for empty container

By scrutinizing the turnover days of empty containers in both random and optimized repositioning scenarios, the results indicate that the average turnover days in the optimized repositioning scenario hover around 25 days, whereas it is approximately 20 days in the random scenario. Illustrated in Figure 5, The optimized strategy's turnover days are five days more than the random strategy's, attributable to meticulous port selection based on profit, distance, and demand considerations in the optimized strategy. The model findings corroborate that the random strategy dispatches empty containers to the nearest or first demanding port without accounting for revenue consequences. In this strategy, the shipping line aims to maximize container operations, even at lower freight values. In contrast, the optimized strategy distributes empty containers through effective pre-planning, ensuring immediate utilization and securing higher freight rates (CMA-CGM, n.d.).

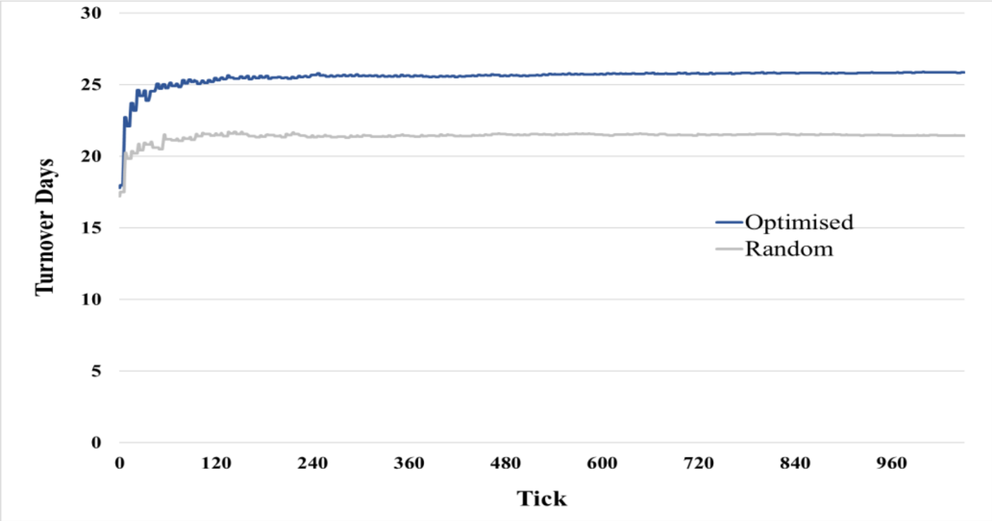

Figure 5. Empty Container Average Turnover Days

As illustrated in Figure 6, the model outcomes depict the frequency of container utilization throughout its lifespan. In the random scenarios, empty containers experience prolonged waiting times in the depot until a vessel arrives, constituting a non-revenue-generating period accompanied by additional costs such as storage expenses. Conversely, in the optimized scenarios, the average idling rates of empty containers are lower than those in the random scenarios, as containers are swiftly dispatched to profitable customers. While the simulation model's results may not exhibit a stark contrast in the idle rates of empty containers between both scenarios, even the slightest difference can lead to a notable change, primarily due to the continuous escalation of storage costs. Consequently, enhancing container utilization has the potential to yield cost savings and preserve the container's lifespan (CMA-CGM, n.d.).

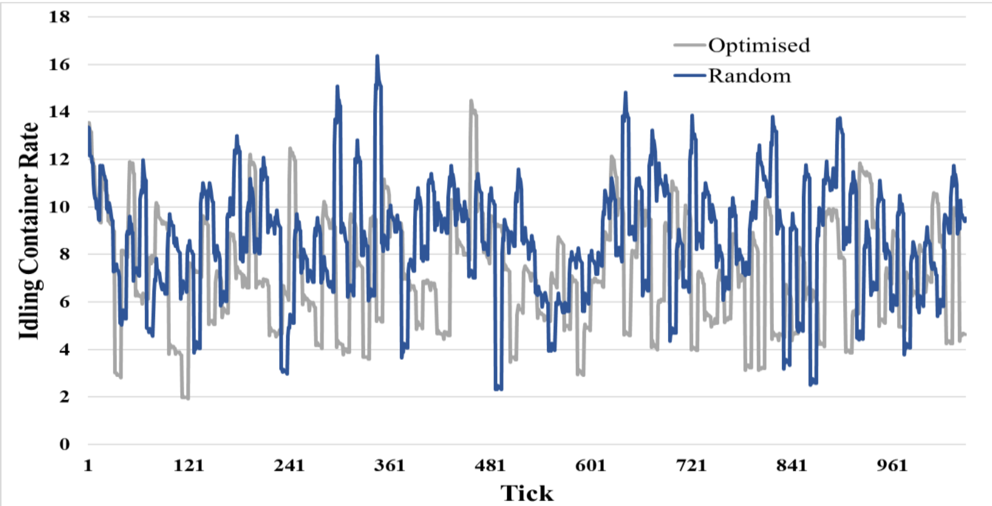

Figure 6. Empty Container Utilization Rates

Comprehensive computational experiments, incorporating sensitivity analyses, demonstrate the practical applicability of the optimization simulation approach, with three key hypotheses validated and endorsed. 1. The optimized repositioning strategy exhibits a positive correlation with company profits, effectively generating lucrative transport networks; 2. The response time for supplying empty containers may experience a slight increase under the optimized strategy, as empties are strategically moved based on factors such as profitability, location, and demand; 3. The optimized strategy results in an augmented container utilization rate throughout its lifespan, attributable to its role as a primary factor influencing this asset's performance.

8. CONCLUSIONS

This study leverages a combination of agent-based techniques and mathematical programming within the realm of maritime logistics to devise a novel model addressing the challenge of managing the movement of empty containers. The hybrid approach capitalizes on the complementary strengths of both techniques, demonstrating significant benefits. Agent-based modelling emerges as a potent tool for shaping decision-making processes in supply chains.

The results affirm that the proposed model holds broad advantages for the global economy, particularly the maritime sector. The model effectively validates three hypotheses, contributing to the enhancement of empty container repositioning. Simulation outcomes underscore the substantial improvement in overall empty container rental profits achievable through the optimization method. In contrast, random allocation methods, such as first-come-first-serve or arbitrary dispatch of empty containers to in-demand ports, may lead to financial losses for shipping companies.

Key characteristics revealed by the model's experimental results include the significant impact of the repositioning strategy on profit, with accumulated net profit increasing as the number of empty containers in the system decreases. Furthermore, the optimized repositioning strategy demonstrates a more pronounced increase in empty container turnover, leading to greater profitability. Additionally, the model's optimized strategy maximizes improvements in container utilization throughout its lifespan.

From a sustainability standpoint, the model showcases that reducing container movements translates to substantial reductions in environmental impacts, including congestion, fuel consumption, and CO_2 emissions.

The proposed model for managing empty container movements offers substantial improvements within the shipping industry on multiple fronts. Firstly, it aids in minimizing capital expenditures and enhancing financial outcomes for shipping lines. Secondly, it addresses resource consumption by reducing inventory levels and safety stock globally, contributing to increased sustainability. Thirdly, the model helps lower depot storage costs and terminal space requirements, providing shipping lines with more storage capacity at reduced charges.

More attention should be paid to analyzing and applying data mining techniques for solving container-related problems. It seems to be fruitful for practitioners as well as researchers. The dual role of many shipping lines as competitors to each other and allies in solving the problems of the maritime sector is an interesting phenomenon that is worth investigating. Therefore, if this study is to be used in future research, the researcher should focus on more comparative studies among shipping players that can enrich the analysis with beneficial results in empty container management. It would also be interesting to use these compassions to evaluate the extent to which different companies are committed to enforcing agreements and the obligation to follow international maritime law.

Another direction of future research is to study situations with multiple means of transportation such as inland and rail transport with various types of containers (e.g., TEU, FEU, dry, and reefer). Taking into account the perspective of different actors in the supply chain of empty containers is vitally important.

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