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Empty Container Return Logistics Optimization in Maritime Transport

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***Abstract*— Managing empty-container is an integral part of an overall efficient global transportation system as they relate to shipping and other means of transportation. Efficient empty container management is required to balance demand and supply between major exporting and importing regions. The movement of containers is not profitable when it comes to an empty return. One of the persistent logistics challenges faced by the liner shipping industry during the last decade is the Empty Containers Return problem (ECR). Ocean carriers and other transport operators are typically facing the challenges of finding effective and robust solutions to ECR problems. The main contribution of this paper is to propose a cost-effective and efficient solution for returning empty containers from one port to the original port based on the Artificial Bee Colony (ABC) algorithm. Computational results show that the proposed solution performs well in terms of computational time and solution quality.**

Keywords*— *Shipping companies; Supply chain; Empty containers; Optimization; Return logistics; Artificial Bee Colony .

I. INTRODUCTION

The shipping industry is the most efficient and safe transport to move mass goods worldwide. Consequently, more than 90% of world trade is carried by sea [1]. In the middle of the twentieth century, containerization was a significant technological development in the shipping industry. It has played an essential role in dramatically reducing the transport cost, which was so expensive before containerization [2]. Containerized maritime transportation has been growing steadily during the past decade. Managing container movements is one of the most challenging logistics problems in the shipping industry.

Container logistics refers to the management of shipping containers throughout the supply chain. Song and Dong [3] classified the container transportation chain into two categories: the supply chain of full containers and the supply chain of empty containers. The movement of containers is not profitable when it comes to an empty return. One of the major logistics challenges faced by the liner shipping industry is the optimization of the empty containers return (ECR) problem. This problem arises when empty containers need to be returned to their point of origin, which can be a costly and time-consuming process.

The ECR problem in maritime transport involves determining the optimal routing and scheduling of empty containers to be returned to their origin port or to another destination port, in order to minimize transportation costs while meeting a demand for container supply at different locations.

II. THE EMPTY CONTAINER PROBLEM

To define the empty container problem, we first describe its dynamics. The typical cycle of a cargo container (see Figure 1) starts when a shipping company takes an empty container from a container depot. The empty container is loaded on a truck and delivered to a shipper, who fills it with the merchandise to be shipped. Once the container has been filled, the company transports it to its final destination, as indicated by the consignee to whom the cargo is to be delivered. Typically, the company uses multiple types of transport. The filled container is transported by truck to the main port, where it will be loaded onto a vessel. Some shippers fill the container at the port, saving the travel from the depot to the shipper's location and then to the port. Once all customs requirements for the filled container at the port have been satisfied, the container is then loaded onto a vessel.

Once loaded on the vessel, the filled container is transported to the port at which it is to be unloaded. The destination port is generally close to the consignee's location. The filled container is unloaded from the vessel and is transported by truck, train, or feeder ship to the consignee's location, at which the consignee receives the container, unloads the merchandise, and returns the empty container to the shipping company [4].

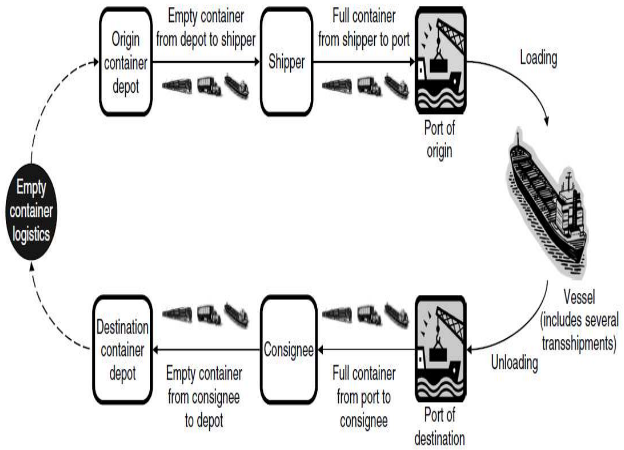

Fig. 1. Typical cycle of a cargo container.

The time and place at which consignees will return empty containers are uncertain because customers sometimes delay returns. The ECR problem is particularly acute, as shipping companies need to manage large volumes of containers across multiple ports and shipping routes. Inefficient management of empty containers can lead to significant costs and delays in the supply chain. Therefore, one of the main objectives of all shipping companies is to reduce ECR costs.

ECR is a NP-hard optimization problem. Metaheuristics is a powerful approach to solving the ECR problem in container logistics. Metaheuristics are algorithms that use search and optimization techniques to find the best possible solution to a given problem [5]. They are particularly well-suited to solving complex optimization problems like the ECR problem. In line with that issue, this paper will explore the use of the Artificial Bee Colony (ABC) algorithm for optimizing the ECR problem in the maritime transportation sector.

III. LITERATURE REVIEW

Based on the literature overview, numerous studies have shown that managing empty containers properly can effectively reduce the cost, improve utilization, and minimize the environmental impact of the empty container movements.

The contribution of the authors in [6] is a part of reverse logistics in the field of Maritime Transport. The objective of this work is to solve the problem of the imbalance of the distribution of containers and look for empty containers at less cost to meet the demands of clients. The approach presented in this work is based on a Taboo Search algorithm. It allows the process of the clients' demands and transfers of full containers as well as the research of empty containers by optimizing the cost of theirs return.

The objective of the work discussed in [7] is to propose a mechanism to provide an optimal return of empty containers in the Maritime Transportation Network (MTN) to maximize clients' demands satisfaction and maximize profitability of the MTN's lines. The authors used an evolutionary heuristics that allows a decision support for the return of empty containers based on the Genetic Algorithms.

In [8], a mathematical model based on linear programming was presented to design a reverse logistics network, with the repairing and remanufacturing options being taken into account simultaneously. The objective function of the model is to minimize the system's total cost involved in managing returned products. On another side, the study [9] presented a reverse logistics network design consisting of three levels design: client returns, collection centers, and factories. The objective function proposed aims to maximize profit, calculated as revenues minus the sum of resales cost of reverse logistics and the price of resolution.

Chou et al. [10] discussed the allocation problem of empty containers in a single service route by proposing a Fuzzy Logic Optimization Algorithm (FLOA). The authors used a fuzzy backorder quantity inventory logic, as a first stage to define the number of empties at ports, considering the stochastic of imports and exports. The second stage is a network flow model, as a mathematical optimization programming to determine the empty containers that should be allocated between ports based on the results in stage one. A case study of the trans-pacific liner route in the real world was applied.

Dong and Song [11] presented a simulation-based optimization approach, to address the empty-container-repositioning problem with fleet sizing in a stochastic dynamic model. The authors combined the GA and Evolutionary Strategy (ES) for the optimization approach to find the optimal fleet size and control policy that can minimize the total costs. They formulated the problem as event driven, meaning that when a vessel arrives or departs, the system's state would update. The complexity of the optimization problem prompted researchers to use the simulation-based evolution, for determining the parameters of empty and laden containers that are transported for each port pair at each event by each vessel. Additionally, another proposal was the subject of the work presented by Song and Dong [12]. Their proposal has addressed the problem of the routing of cargo shipments and the problem of repositioning empty containers at an operational level for a shipping network with several service lines, multiple ships deployed and multiple regular trips. The researchers have proposed a modeling with an integer linear-programming combined with a heuristic method to minimize the total cost of the planning.

Alfandari et al. [13] discussed the problem of designing network routes on a barge container shipping company. This study aims to maximise the company's profit, by identifying a sequence of calling ports and the size of the fleet between each pair of ports. Therefore, the authors proposed a mixed-integer programming model with two formulations: the first needs arc-variables for modelling empty containers, while the second requires node-variables for handling those empties.

Shintani et al. [14] dealt with the transportation of full and empty containers. The authors also took into account the combinable containers and developed a minimum cost multi-commodity network flow model. The study showed that mixed use of both standard and combinable containers can provide significant cost savings.

IV. CONTRIBUTION

The empty containers returning process begins when full containers are delivered to surplus ports. When a new customer in a deficit port requests empty containers from the shipping company, the latter checks its empty stock with surplus depots and orders the requested number of empty containers. Customers can order any number of containers, and the shipping line will provide them by availability. The total number of requested empty containers is transported from one surplus port to a deficit port according to surplus port' empty containers availability. Despite the length of this cycle, including its risks and costs, shipping lines can gain more revenue from this process instead of paying storage costs for empties containers while waiting for an order in the surplus ports.

Our proposed approach assists the shipper when a need for empty containers is observed in certain ports of the maritime network, by providing an optimal solution to find the port from which empty containers can be returned with minimal cost to satisfy its customers based on the Artificial Bee Colony (ABC) algorithm. Before detailing the proposed approach to address the ECR problem, we will explain the ABC algorithm.

A. Artificial Bee Colony algorithm

The Artificial Bee Colony (ABC) algorithm is a population-based optimization algorithm inspired by the foraging behavior of honeybee colonies. It was first introduced by Dervis Karaboga in 2005 [15] and developed by Karaboga et Basturk [16].

In the ABC algorithm, a colony of artificial bees searches for the optimal solution to a given optimization problem. The bees are classified into three types: employed bees, onlooker bees, and scout bees. Each employed bee represents a candidate solution to the problem and searches the solution space around its current position. The onlooker bees select promising solutions based on the information shared by the employed bees and then decide whether to become employed on the corresponding food source. The scout bees are responsible for exploring new solutions by randomly generating new solutions.

The ABC algorithm operates in a cycle of three phases: the employed bee phase, the onlooker bee phase, and the scout bee phase. In the employed bee phase, each employed bee improves its current solution by searching the neighboring solutions. In the onlooker bee phase, the onlooker bees select the solutions with the highest fitness value from the employed bees based on their probabilities. In the scout bee phase, the scout bees generate a new random solution if they cannot find a better solution after a certain number of iterations. The performance of the ABC algorithm depends on the number of bees in the colony, the number of iterations, and the problem being solved. The ABC algorithm has shown good performance in various optimization problems and has become a popular optimization algorithm in the research community.

B. Adaptation of the ABC algorithm to address the ECR problem

The study uses the ABC algorithm in a shipping network to optimize empty container search and maximize total profit. Figure 2 illustrates the process of ABC optimization. The cycle starts when the customer C_j requests empty containers CO_j from the shipping company to load cargo. Based on customers' demand, the shipping company orders empty containers from a surplus port P_j to a deficit port P_i. Customers can order any number of containers $\{CO_1, CO_2. . . CO_M\}$, and the shipping company will provide them by availability $\{CC_1, CC_2. . . CC_M\}$.

To draw an analogy between bees searching for food in nature and bees searching a port in our optimization problem addressed in this study, we provide an overview of the adaptation of the ABC algorithm to tackle the ECR problem.

TABLE I. NATURAL BEES VS ARTIFICIAL BEES

Bees in nature	**Artificial Bees**
The beehive	Deficit port
The food source	surplus port
The nectar quantity	Requested empty containers
The nectar quality	Transportation cost of returning empty containers

The proposed ECR Optimization approach starts with a random number of CC_j, then select only ports having sufficient empty containers ($CC_j \geq CO_j$). The ABC algorithm starts exploring the solution space to gradually reduce the total cost (which represents the fitness function). After multiple runs, the best solution (port P_j) which empty containers can be returned with minimal cost. The shipper in the deficit port Pi must pay this amount and satisfy their customer's request.

To implement the ABC algorithm for the ECR problem, we would need to define appropriate fitness function that evaluate the cost of transporting each container. The fitness function is calculated according to the distance between each pair of ports, the number of empty containers in the port of destination and the cost of transporting an empty container according to the formula (1).

$$C_{ij} = P_u * Dist_{i,j} * \mathrm{CO}_j \qquad (1)$$

- $C_{i,j}$: The transportation cost of empty containers, that are returned from a port P_j to the requesting port P_i.
- P_u : The unit price for transportation of one empty container.
- $Dist_{i,j}$: The distance between the requesting port P_i and the sender port P_j .
- CO_j : The number of empty containers, to be transported to the port P_i.

The Objective of our fitness function is to minimize the total transportation cost of returning empty containers to their origin port depending on distance between ports and availability of empty containers.

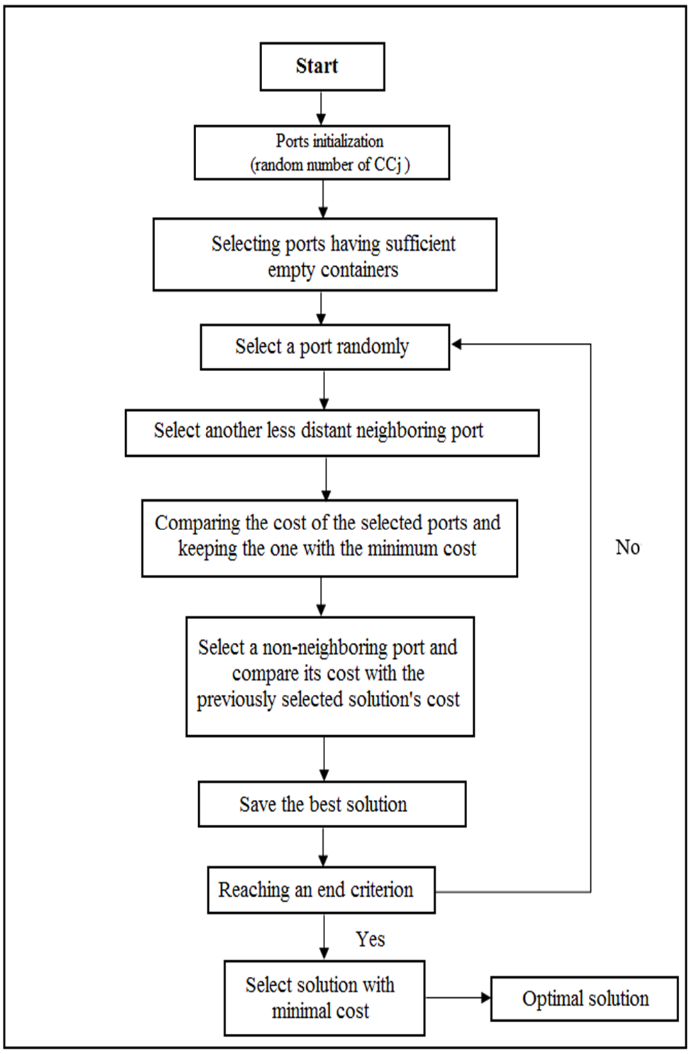

Fig. 2. ABC algorithm for Empty Container return Optimization.

The proposed approach considers the following constraints:

- *Availability constraint* : When searching for a neighboring port, the proposed approach look for the port that has the most empty containers available in order to keep a balanced distribution on the network but with the controlling of the return's cost if it is not fairly high compared to the return's cost from another port that has less empty containers in its stock. If a quantity of empty containers requested is not found on all ports of the MTN, the method cannot guarantee a total, but a partial solution.
- *Constraint of empty container transportation' costs* : each empty container has to be transported with a cost calculated unit "µ" compared to the distance between the ports. This cost must be as minimal as possible for the shipper.
- *Distance constraint* : The distance between each pair of ports should be the most optimal for ensuring a maximum gain to the company (the cost is proportional to the distance).

V. EXPERIMENTAL RESULTS

JAVA NetBeans software has been used to implement the proposed ABC algorithm. In this section, we give some numerical examples to illustrate how proposed approach affects empty container returning at the requesting port Pi and how the cost changes. Our proposed ABC algorithm is tested on several different topologies: topologies with 10, 20, 50, 100, 200, 500, and 1000 ports, to observe the influence of system density on the performance of our algorithm. The ABC parameters used in our approach are as follows:

TABLE II. IMPLEMENTATION SETTINGS

Settings	Values
Number of ports	10,20,50,100,200,500,1000
Number of empty containers	Between 0 and 100
price for transportation of one empty container	Between 1 et 1000µ
position (x,y) of each port	Between 0 and 50

The transport price of an empty container on a shipping line in units is 1µ to 1km of distance.

Our proposed ABC algorithm allows finding the port with the requested number of empty containers at a lower cost by using different topologies and different parameters. Figure 3 illustrates an example of the test result on a 10-ports topology.

To see the effectiveness of the proposed ABC algorithm, we compared the ABC algorithm for searching empty containers with the random search method (without ABC) in regards to the return' price of empty containers (cost with ABC and cost without ABC respectively, see Table III).

Fig. 3. Test result on a 10-ports topology

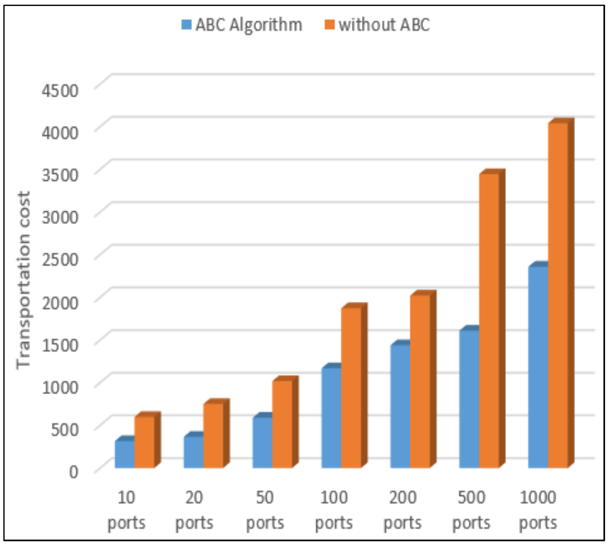

Fig. 4. Implementation Results

TABLE III. IMPLEMENTATION RESULTS

Topology	**deficit port Pi**	**surplus port Pj**	**requested empty containers**	**transport cost with ABC**	**transport cost without ABC**	**iteration**
10	Port 3	Port 2	74	317	599	10
20	Port 4	Port 3	104	366	752	10
50	Port 3	Port 31	120	590	1020	10
100	Port 25	Port 19	152	1170	1874	10
200	Port 65	Port 27	134	1440	2022	20
500	Port 2	Port 326	180	1610	3445	50
1000	Port 5	Port 549	278	2360	4042	50

Table III summarizes the results comparison of our ABC algorithm with the random search method (without ABC) for the different topologies used. Several tests were conducted in order to obtain these optimal values. For example, in 10-ports topology scenario, it can be observed that the algorithm has successfully found the optimal solution (port 2) having the number of empty containers (74) requested by port 3, with a cost of 3172µ within a period of 12 seconds. According to several tests carried out, the optimal solution is found at the 10th iteration.

Figure 4 allows visualization of the variation in the transportation cost for returning empty containers when a deficit port Pi cannot satisfy customer demand. We notice that the cost of transporting empty containers through the proposed ABC algorithm is clearly less expensive than the transport done without the ABC algorithm for different topologies

VI. CONCLUSION

The global trade imbalance among different areas leads to the movement of empty containers from a surplus area to a deficit area where customers demand, leading to high costs and the lack of optimal utilization of the containers. Optimizing empty container logistics is a critical aspect of shipping operations that can significantly improve supply chain efficiency. This paper has highlighted the importance of optimizing the return logistics of empty containers in maritime transport and how optimization algorithms can be used to solve this problem. Our objective is to propose a cost-effective and efficient solution for returning empty containers from one port to the original port using the ABC algorithm. Based on the computational experiments that we conducted, the ABC algorithm has greatly improved the efficiency and cost-effectiveness of empty container return logistics, leading to reduce transportation costs.

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