Hindawi
Mathematical Problems in Engineering
Volume 2020, Article ID 3528026, 12 pages
https://doi.org/10.1155/2020/3528026

Research Article

Yield Management by Reconstruction of Cargo Contribution for Container Shipping

Yisong Lin[1], **Xuefeng Wang**[1] **and Jian Gang Jin**[2]

[1]*Shanghai Maritime University, Logistics Engineering and ResearchCenter, Shanghai, China*
[2]*Shanghai Jiao Tong University, School of Naval Architecture, Ocean & Civil Engineering, Shanghai, China*

Correspondence should be addressed to Yisong Lin; 17068495@qq.com

Received 3 April 2020; Revised 15 May 2020; Accepted 21 May 2020; Published 16 June 2020

Academic Editor: Frederic Kratz

This study provides a cargo contribution yield management model to solve the ship capacity control problem for the container liner shipping industry. We propose a new objective to optimize cargo contribution to replace the focus on total revenue or average revenue in the current research. We reflect the special characteristics of yield management in container liner shipping, and all cost items were identified and calculated to develop a new cargo contribution evaluating system. We propose a mathematical model for service route segments' allocation distribution based on cargo contribution. We use a genetic algorithm to solve the model further with comparative analysis with actual practice. The study cultivates new ground in the current literature with a wide range of innovative applications at a practical level.

1. Introduction

Yield management (YM), alternatively known as revenue management (RM) is a practice that originated in the airline industry in the 1970s following the deregulation of the US airline market. The practice has been successfully applied to airlines, hotel management, and retail management. However, the research on YM for container liner shipping service is scant. There are few articles published in the last 50 years after filtering out irrelevant studies, and the unique features and usability of models developed for air transport remain unclear [1]. The main characteristics of YM application noted by Hellermann include perishability, fixed capacities, high fixed costs versus low marginal costs, stochastic demand, advance bookings, demand segmentation, and the possibility of collecting historical data [2]. The conformity of YM in container liner shipping was well presented in the previous research by Ting and Tzeng; however, when addressing YM in container liner shipping, the distinct characteristics should not be neglected, and the objectives, constraints, and models should be adjusted accordingly [3]. The YM for container shipping differs from revenue management for airline passengers. Most airline passengers travel on return itineraries, so that passenger flow balance comes naturally. In contrast, a typical container shipment travels only one way, and there is significant imbalance in container shipments. That necessitates empty container repositioning, a problem that is not encountered in airline passenger transportation. In addition, in container shipping, a large fraction of containers are shipped under the terms of long-term contracts between carriers and shippers. Therefore, in the different booking orders, the price of some orders has been locked, while some others depend on the spot market. In contrast, most airline tickets for passengers are bought on the spot market, and the prices can change at any time. Weatherford and Bodily presented a whole picture of the basic structure of YM research and found that the objectives were focused on maximizing profit, maximizing capacity utilization, maximizing average revenue, maximizing total revenue, maximizing net present value, minimizing lo st customer goodwill, and extracting each customer's maximum price [4]. The related costs associated with revenue have been neither systematically defined nor fully reflected in decision-making objectives. The cargo contribution related to the balance area or imbalance area also has not been well reflected. Gordon et al. analysed the weakness of the existing revenue measure and concluded that factors such as cost, utilization, the demand related to a change in service price, and seasonality should be incorporated; however, the proposed new yield optimization measure still focuses on the increase in revenue per capacity unit [5].

Meng et al. presented a summary of the YM problem for container liner shipping services and concluded that the YM problem is composed of ship capacity control and pricing for shipping services. This paper proposes an optimization model based on cargo contribution evaluation (here, we define the difference between cargo revenue and the apportioned cost calculated by cost logic as cargo contribution). The model maximizes the overall cargo contribution instead of total revenue, profit, or capacity utilization in the previous research studies.

The contribution of this study is threefold. First, the study reflects the special characteristics of YM in container liner shipping and proposes a new optimization model to solve the YM ship capacity control problem. The new research idea is based on the reconstruction of cargo contributions, which reflects both cargo revenue and cost. The cost-apportioned logic is established by the business process of the participative observation, which solves the problem of dealing with evaluating of empty container repositioning fee. Second, the study analyzes the complete shipping cycle and identifies all the cost items associated with container shipping and formulates an optimization problem of allocating container slots. The new idea based on cargo contribution evaluation provides a new direction for future research. Third, the optimization model reflects not only the contribution difference between long-term customer and spot market customers but also the difference caused by quantity discount, cargo flow direction, and cargo category. This has significant practical contribution through case study verification.

The remainder of the paper is organized as follows: Section 2 presents a literature review and analyzes the gap in the research that this study fills. Section 3 discusses the capacity control problem. Section 4 formulates a slot allocation model through mathematical programming. Section 5 provides a case study with a genetic algorithm (GA) solution. Section 6 presents the conclusion.

2. Literature Review

Yield management (YM) is a practice that originated in the airline industry; therefore, the earlier studies were focused on demand forecasting, overbooking control, dynamic pricing, and seat allocation in the airline industry. Littlewood, Lee and Hersh, and McGill studied the demand forecasting problem [6–8]. Weatherford and Bodily, Robinson, Belobaba and Farkas, Chatwin, and Liang studied the overbooking of airline passenger revenue management [4, 9–12]. Feng and Gallego, Feng and Xiao, and Gallego and Van Ryzin studied on dynamic pricing in air passenger transport [13–15]. Glover et al., Belobaba, Curry, and Brumelle studied on seat allocation in the airline industry [16–19]. The research extended to railway transportation, hotel management, and car rental management accompanied by in-depth study and significant achievements in the application in the airline industry.

The research of yield management in container shipping began in the 1990s. Brooks and Button analysed the pricing structure and proposed a potential application of yield management in container shipping [20]. Ha studied the allocation and pricing problem in container shipping and proposed a possible yield management solution [21]. Maragos proposed an allocation management and pricing model [22]. Subsequently, the research on yield management in container shipping increased but is still very limited in general. Meng et al. presented a critical review of RM for container liner shipping services. The authors concluded that the RM problem is composed of ship capacity control and pricing for shipping services. However, there are few articles after filtering out irrelevant studies. The following gaps were found by their research: some of the characteristics of containerized cargo are not fully considered; constraints such as the number of refrigerated container slots are not considered; and the differing behaviours of spot markets and long-term markets are not reflected. The future research directions proposed focus on demand forecasting, customer behaviour modelling, dynamic capacity control, and dynamic pricing determination. We present the main literature in container shipping as shown in Table 1.

Given the above, the existing literature already well reflected the constraints of the objectives, which include limitations on total capacity, vessel deadweight, and the number of plugs for reefers. The existing literature also addresses demand segmentation. The special characteristics of demand segmentation include the container types (e.g., dry or reefer), container sizes (e.g., 20 ft or 40 ft), and freight contracts (i.e., long-term or spot). Most of the current studies achieved consistency in this point. However, the objectives showed great differences in the study of ship capacity control in YM. We found the following limitation in the current research on the practice of container liner shipping. First, the definition of objective function is unreasonable. The objectives were mostly based on the optimization of average revenue or total revenue while the corresponding costs were not reflected. Second, the characteristics of yield management for container shipping which distinguish from other industry are not systematically identified. The ignorance of cost and its apportioned logic may cause deviation. The incomplete evaluation of related factors (such as quantity discount, cargo flow direction, and cargo category) may affect applicability in practice. Third, most of the existing literature focuses on the overall allocation strategy, but few research studies focus on service route segment allocation management (here, we define the path between different nodes in the service network as "service route segment"). This is what this paper intends to contribute to the current literature.

3. Problem Description

The container liner service route is composed of various loading ports and discharging ports on a weekly service

Table 1: Previous literature report of YM for container shipping (source: summarized by the authors).

Literature reports	YM problems	Main contribution	Limitation
Brooks and Button	Dynamic pricing strategy	Analyzed the pricing structure and proposed a potential application of yield management in container shipping	Proposed an overall application suggestion, without clear solution
Ha	Allocation control and pricing	Proposed an allocation control and pricing model	Evaluated revenue while cost was ignored, and the special characteristics of shipping were not reflected
Maragos	Allocation control and pricing	Proposed an allocation control and pricing model	Evaluated revenue while cost was ignored, and the special characteristics of shipping were not reflected
Ting and Tzeng	Allocation management	Proposed a conceptual model for liner shipping revenue management (LSRM) and recognized the special characteristics of empty container reposition of YM for container shipping	The empty container reposition fee, which is a variable cost, was calculated repeatedly in the objective function while cargo costs, transportation costs, equipment costs, vessel costs, and fuel cost were not reflected
Gordon et al.	Allocation management	Analyzed the weakness of the existing revenue measure and concluded that factors such as cost and utilization should be incorporated	The proposed new yield optimization measure still focuses on the increase in revenue per capacity unit
Zurheide and Fischer [23]	Allocation management	Proposed a slot allocation model to maximize expected profits through booking limits to different demand segments	The empty container reposition cost, container leasing, and storage costs were reflected in the slot allocation without distribution in the whole service network
Zurheide and Fischer [24]	Booking order control	Presented a booking limit strategy, nested booking limit strategy, and bid-price strategy based on the booking class defined by combined segmentation	The slot allocation model was evaluated by the average price and average cost without considering cost logic
Wang et al. [25]	Seasonal revenue problem	Proposed multitype container selection, routing, assignment, and sailing speed in each shipping leg of the service network	The model focused on maximizing seasonal profit; however, only operating cost was evaluated without considering cost logic.
Feng and Chang [26]	Allocation management	Optimized the space allocation model so that the same model is applicable to the complex port-to-port slot distribution networks of Asian port	Costs were not fully evaluated and empty container reposition cost was simply apportioned in the network without considering cost logic
Lee et al. [27]	Allocation management	Proposed control model for allocation distribution and recognized the special characteristics of empty container reposition of YM for container shipping	Costs were not fully evaluated and empty container reposition cost was simply apportioned in the network without considering cost logic
Lu and Mu [28]	Slot reallocation planning	Proposed an allocation control model under the circumstances of vessel delay and port operation restriction and recognized the special characteristics of empty container reposition of YM for container shipping	Available only under specific circumstances, and empty container reposition cost was simply apportioned in the network without considering cost logic
Liu and Yang [29]	Allocation management specially for sea-rail intermodal transportation	Proposed a two-stage slot control optimization mode to maximize expected revenue	Costs were not clearly identified and calculated for cargo contribution analysis, and the YM objective was not well reflected in the objective function

frequency. Correspondingly, the service route can be divided into several different segments according to the loading port and discharging port. Taking a service route of AEU3 from COSCO Shipping Lines as an example, as shown in Figure 1, the service route consists of six calling ports in the Far East and four calling ports in Europe.

The service route can be divided into 24 westbound segments and 24 eastbound segments, as shown in Table 2.

There is a trade imbalance between the westbound and eastbound segments. For example, in 2008, 17.7 million TEUs (twenty feet equivalent units) were transported from Asia to Europe, and only 10 million TEUs were transported from Europe to Asia (UNCTAD 2008) [30]. Therefore, the empty container reposition constitutes a special characteristic of YM for container shipping.

It is common practice to allocate slots to each loading port with relatively fixed numbers, and the local office on container liners is responsible for local slot control. The main advantage of this practice lies in clear responsibility and easy management; however, the weakness is prominent as dynamic allocation management cannot be applied to improve the cargo contribution. The cargo contribution

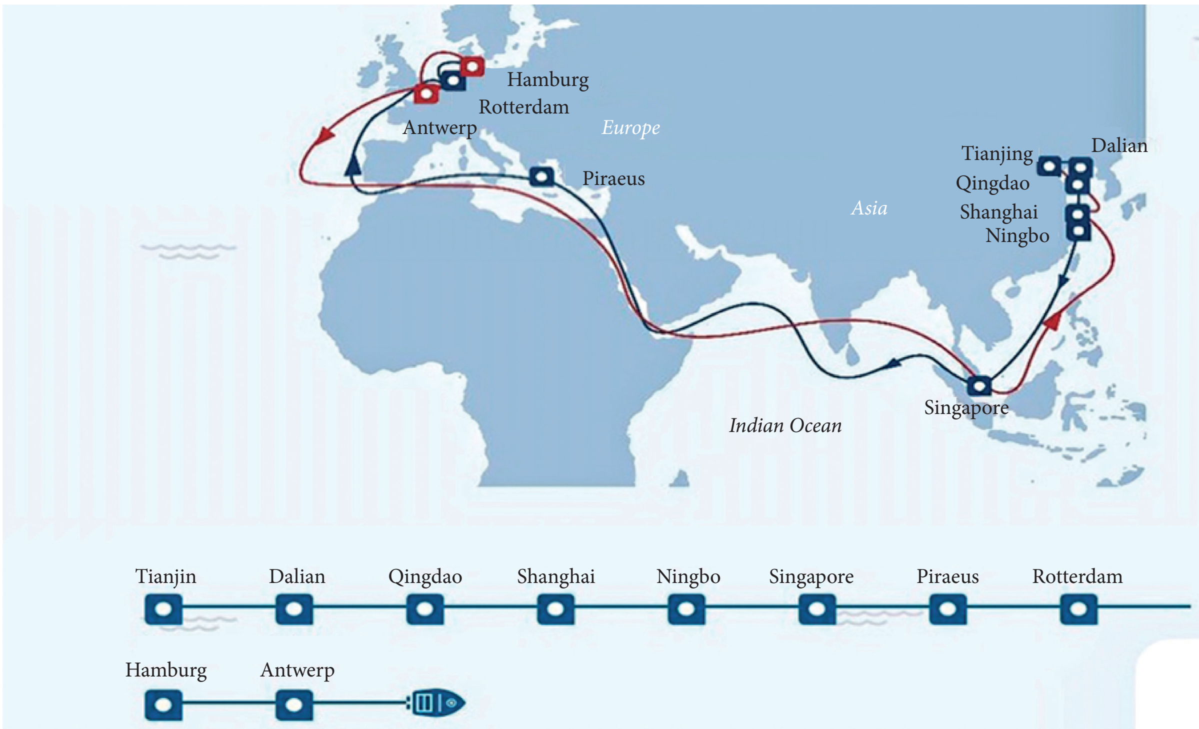

Figure 1: The AEU3 service route from COSCO Shipping Lines (source: http://lines.coscoshipping.com).

Table 2: Westbound and eastbound segments of the service route AEU3 (source: summarized by the authors).

Westbound segment		Eastbound segment	
Loading port	Discharging port	Loading port	Discharging port
Tianjin	Piraeus	Piraeus	Tianjin
	Rotterdam		Dalian
	Hamburg		Qingdao
	Antwerp		Shanghai
Dalian	Piraeus		Ningbo
	Rotterdam		Singapore
	Hamburg	Rotterdam	Tianjin
	Antwerp		Dalian
Qingdao	Piraeus		Qingdao
	Rotterdam		Shanghai
	Hamburg		Ningbo
	Antwerp		Singapore
Shanghai	Piraeus	Hamburg	Tianjin
	Rotterdam		Dalian
	Hamburg		Qingdao
	Antwerp		Shanghai
Ningbo	Piraeus		Ningbo
	Rotterdam		Singapore
	Hamburg	Antwerp	Tianjin
	Antwerp		Dalian
Singapore	Piraeus		Qingdao
	Rotterdam		Shanghai
	Hamburg		Ningbo
	Antwerp		Singapore

shows substantial difference in each service route segment in terms of five aspects. First, the cargo flow (for example, port pair and destination) has a significant impact on the contribution by calculating the empty container reposition cost and the drop-off cost due to a significant difference in the surplus or shortage areas. Second, the cargo structure (for example, cargo owners or forwarders) has a significant impact on the contribution due to the different customer pricing policies. Third, the freight rate contract types (for example, long term or spot) have a significant influence on the contribution due to the rate difference between a long-term deal and the spot market. Neither long-term deals nor the spot rate is always at a low level, and both change dynamically with market fluctuations. Fourth, the proportion of overweight cargo and light cargo in different segments also has a significant influence on contribution. YM in the container liner shipping is restricted by both total capacity and vessel deadweight; the overweight cargo should be balanced with light cargo to improve utilization. Fifth, container liner's strategy and product competitiveness (for example, delivery time, on-time performance, and uniqueness) lead to difference of pricing strategies, which have a substantial influence on cargo contribution. In short, the contribution difference in each service route segment allows the container liners to allocate the slot according to the cargo contribution evaluation to carry out YM management in the industry.

In addition, wide fluctuations and short freight rate floating cycles make YM necessary in container liner shipping. Figure 2 shows that since 2009, freight rate fluctuation has increased with shortened cycles. The traditional way to allocate the slot under the first come, first served (FCFS) principle seems to be out of pace as low contribution cargos account for the majority of loaded cargos in practice.

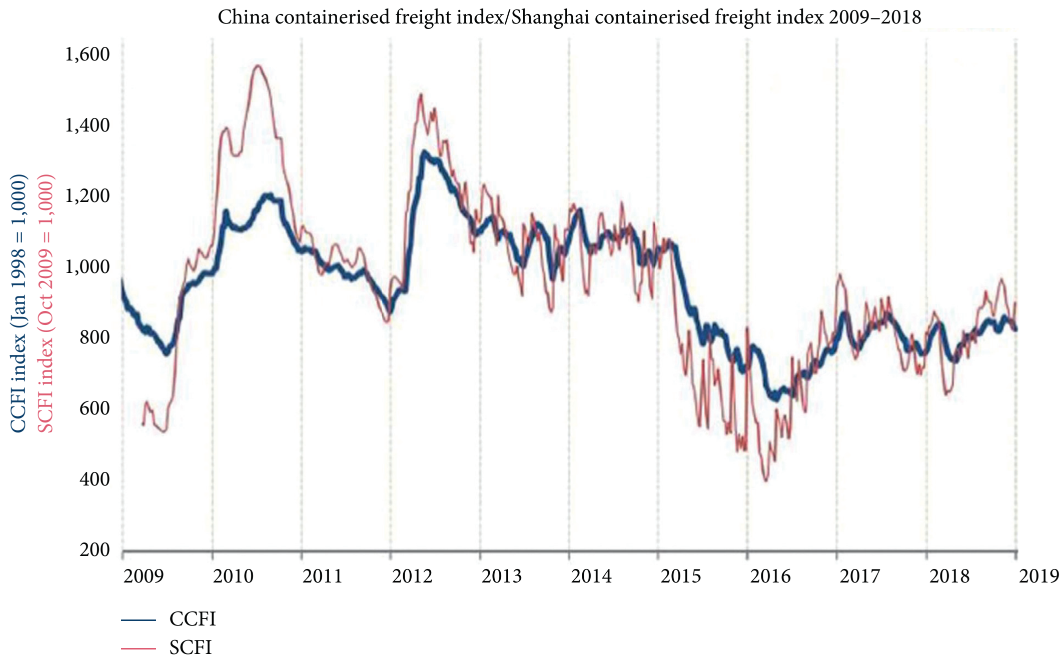

Figure 2: CCFI and SCFI indexes from 2009 to 2018 (source: Alphaliner weekly newsletter 2019, issue 1).

Therefore, we propose a new optimization model through cargo contribution evaluation. We identify all cost items associated with container shipping and formulate an optimization problem of allocating container slots. We present the cargo contribution YM model in Section 4.

4. CCYM Model

4.1. Reconstruction of Cargo Contribution. Figure 3 shows the complete shipping cycle that involves the empty container issue, the extraction of the empty containers from loading ports, the loading of containers at factories, the full containers entering ports, the discharging and delivery at the destination, and the repositioning of empty containers.

In many of these links, calculating the costs for the container liners is a complex process. Some costs are directly associated with shipments. These costs should be directly related to the shipments generating the costs. Some costs, however, must be apportioned in the service route network as these costs are generated as public investments by the container liners to provide network services and products. In addition, some costs must be distributed according to the operated zone (for example, the empty container reposition fee). This is because the imbalances both inbound and outbound are caused by the interaction of several different areas. Therefore, it is only reasonable to combine this area as an operated zone and apportion of the empty container reposition fee to the whole operated zone.

Following this logic, we identified 36 subdivision costs that can be classified into seven categories as shown in Table 3.

4.2. Indices, Parameters, Sets, and Decision Variables

4.2.1. Indices, Parameters, and Sets

C_i: the freight rate of customer i in transport

T_i: the transportation cost for customer i

P_i: the port cost for customer i

EF_i: the equipment fixed cost occurring in the transport of customer i

VC: vessel cost

FC: fuel cost

CMTX1: contribution I

CMTX2: contribution II

CMTX3: contribution III

CMTX4: contribution IV

I: the grade of contribution (taking CMTX4 as a comparison), $I = 1, 2, 3, \ldots$

J: ODF (origin destination flow) for clients, $J = 1, 2, 3, \ldots$

f_t: the contribution of customer flow (fare origin destination flow) per unit

t: the order in which the contribution of the customer flow is arranged (from high to low), $t = 1, 2, 3, \ldots I * J$

d_t: the demand under the different contributions of customers in the segments for allocation

$A_{t.k}$: the matrix that contributes to the customer flow

k: the sequence number of the segment, $a_{t.k} = 0$, $k = 1, 2, 3, \ldots, K$

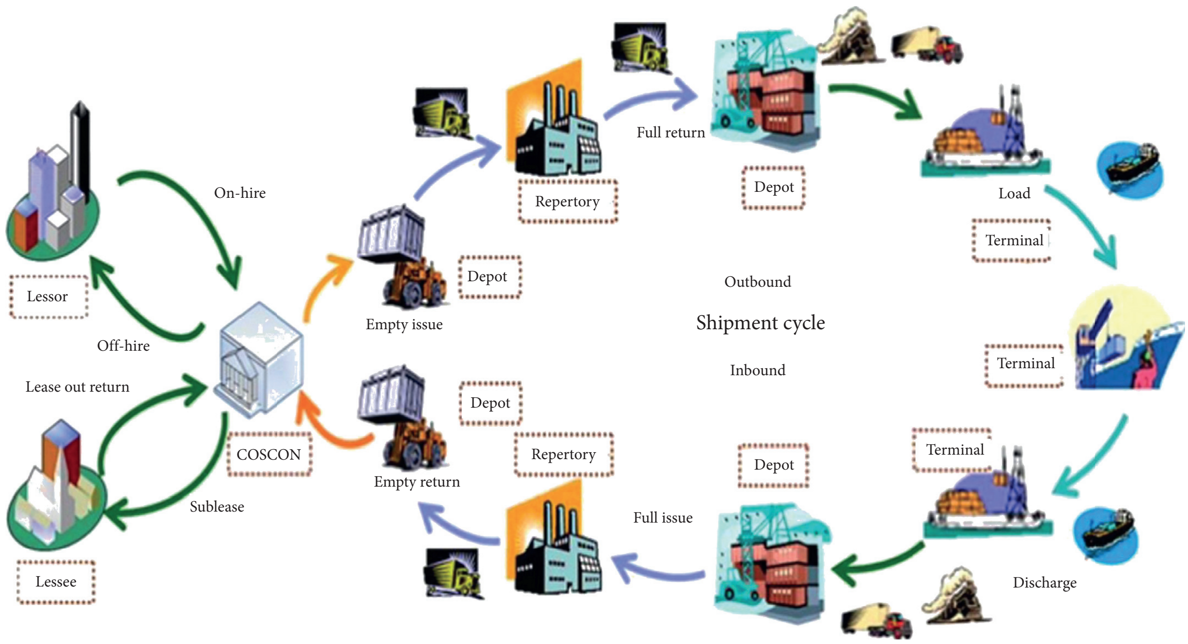

Figure 3: The shipment cycle in container transportation (source: COSCO Shipping Liners Company Limited).

c_k: the number of slots in section k
C: the K vector composed of all c_k
w_k: the corresponding weight of the k segment
W: the K vector composed of all w_k
w_t: the weight of the k customer flow
DW: a t dimension vector composed of all w_t
CTW_t: the contribution of t customer flow

4.2.2. Decision Variables

s_t: the contribution of the customer flow for customer k
S: a t dimension vector composed of all s_t

4.3. CCYM Model Formulation. The different contribution levels are introduced to evaluate how cargo revenue compensates for different costs. Figure 4 shows the different contribution levels by calculating the difference between cargo revenue and various costs in the shipment cycle in container transportation:

$$\text{CMTX1} = CR - C_i - T_i, \tag{1}$$

$$\text{CMTX2} = CR - C_i - T_i - EV_i, \tag{2}$$

$$\text{CMTX3} = CR - C_i - T_i - EV_i - EF_i, \tag{3}$$

$$\text{CMTX4} = CR - C_i - T_i - EV_i - EF_i - VC - FC - P_i. \tag{4}$$

Constraint (1) calculates the difference between cargo revenue and cargo cost and transportation cost, which implies the revenue should be able to cover the cost paying for cargo directly and its transit cost through feeder, rail, and truck in balancing areas. Therefore, contribution I can be used as the bottom-line price for balancing areas under rational competition environment. Constraint (2) calculates the difference between cargo revenue and cargo cost, transportation cost, and equipment variable cost. The empty container repositioning fees and storage fees are well reflected together with cargo cost and transportation cost, which implies that the revenue should be able to cover the cost paying for cargo directly and its transit cost and empty container reposition cost. Therefore, contribution II can be used as the bottom-line price for unbalancing areas under rational competition environment. Constraint (3) reflects the equipment fixed cost, which can be used as the equilibrium price under rational competition environment. Constraint (4) calculates the difference between cargo revenue and cargo cost, transportation cost, equipment variable cost, equipment fixed cost, vessel cost, fuel cost, and port cost. The empty container reposition fees and storage fees are well reflected according to the cost-apportioned logic in practice. The unique characteristics of yield management in container shipping due to cargo flow direction, cargo category, cargo weight, and service route are well reflected through the evaluation of various costs.

According to the actual statistical analysis, we assume that demand d_t is a positive random variable basically in obedience with the normal distribution. That is, with $d_t \sim N(\mu_{ij}, \sigma_{ij}^2)$, d_t is independent of each other. At the same time, the total slot and weight limits of the known vessels remain unchanged after a vessel is deployed into the service route. Without considering the shutout after the booking is released, we study a stochastic programming model for multisection slot control based on contribution reconstruction. For any contribution segment,

Table 3: Cost details in the container liner transportation (source: summarized by the authors).

Cost category	Subdivision cost	Cost calculating logic
Cargo cost	Loading and discharging cost Tally cost Overtime cost Receiving and delivery cost Storage cost On dock rail handling cost Tonnage assessment fees Gate in fees Gate out fees Reefer power and monitoring fees Laden container agency fees Depot costs	Calculated to corresponding shipments
Transportation cost	Transportation cost by feeder Transportation cost by rail Transportation cost by truck	Calculated to the transportation shipments
Port cost	Canal fees Berthing cost Tonnage dues Tug and towage fees Pilotage fees Harbour dues Escort boat fees Vessel agency fees	Apportioned by all shipments in the port pairs
Equipment variable cost	Empty container reposition fees Empty container storage fees Container agency fees	Calculated by the operated zone creating the imbalance
Equipment fixed cost	Container rental fees Container maintenance and repair fees Hanger container fees Chassis and reposition fees Demurrage and detention cost	Apportioned in the service route network
Vessel cost	Vessel construction cost Vessel rental cost Vessel maintenance cost	Apportioned in the service route network
Fuel cost	Fuel cost	Calculated by vessel and apportioned by all shipments in the vessel

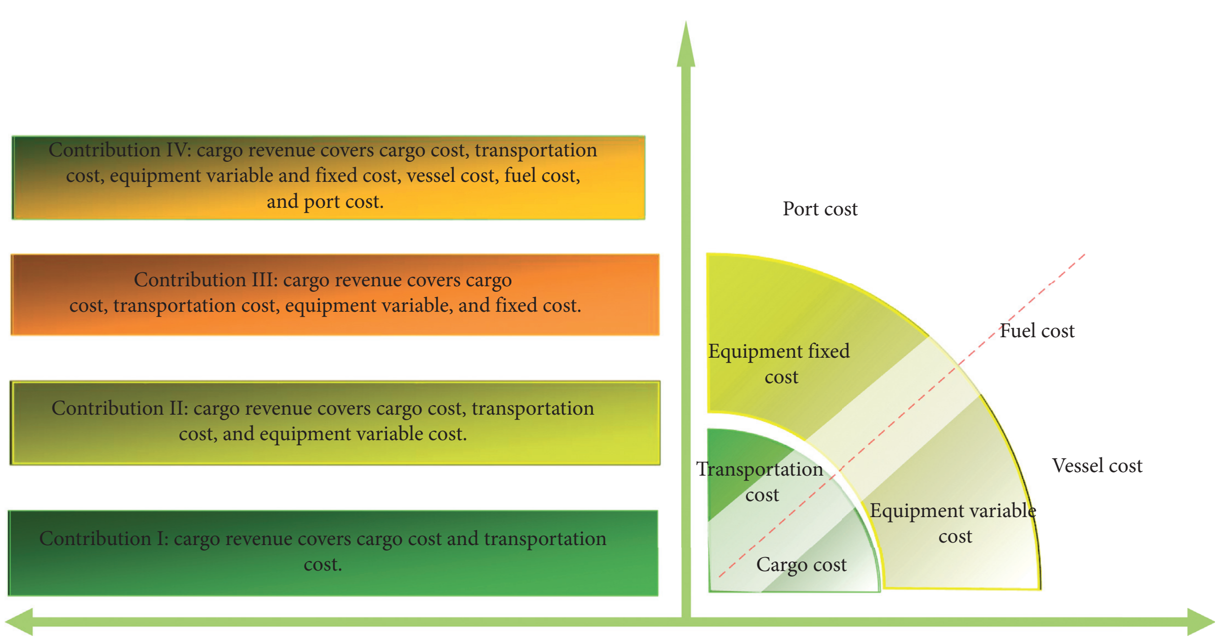

Figure 4: Comparisons of different contribution levels (source: summarized by the authors).

$$CTW_t = f_t \min(d_t, s_t). \quad (5)$$

Since d_t is a random variable, under the premise of known distribution, we express the expected payoff above as the following:

$$E(CTW_t) = f_t\left[\int_0^{s_t} x_t p(x_t)dx_t + s_t\int_{s_t}^{\infty} p(x_t)dx_t\right]. \quad (6)$$

In the formula, $p(x_t)$ is the probability density function of d_t (expressed as the dummy variable x_t):

$$\max_s\left[E\left(\sum_{t=1}^{I*J} CTW_t\right)\right], \quad (7)$$

$$\text{s.t. } A_{kt} * S \le C, \quad (8)$$

$$A_{kt} * W \le DW, \quad (9)$$

$$s_t \ge 0, \quad s_t \in N \quad (10)$$

$$w_t \ge 0. \quad (11)$$

Equation (7) is the objective function of the model. The function objective is to allocate S on all contributing segments so that the total contribution of the whole route is the largest. Constraint (8) indicates that the sum of the allocation assigned in each segment cannot be higher than the total allocation. Additionally, constraint condition (9) indicates that the sum of the weight assigned related to the allocation in each segment is not higher than the total weight limit of the route. Constraint condition (10) indicates that the number of the allocation assigned in each segment must be positive and only the integer. Constraint condition (11) shows that the amount of the segment's weight distribution must be positive.

5. Solution Methodology

Genetic algorithm is a very widely used heuristic algorithm, which has the characteristics of high efficiency and stability when solving large-scale complex optimization problems. It is suitable for solving the mathematical model established in this paper. Therefore, the genetic algorithm is in search for the optimal solution, and the number of booking requirements for each customer is determined to maximize the contribution of the entire route. The main steps of the genetic algorithm are designed as follows:

Step 1. Encoding. Due to the large number of variables, if binary coding is used, overflow may occur. Therefore, the floating point coding method is applied. This model takes the different booking plans of decision-making customers as chromosomes, that is, one booking plan represents a chromosome; each chromosome is composed of two parts, which are the customer number and the number of customer booking requirements. The chromosome coding is shown in Table 4. Among them, for each s_t only takes values between $[0, \mu_{ij} + 2\sigma_{ij}]$, in order to narrow the search scope and reduce the running time, therefore, the following constraint is added to the original model:

Table 4: Chromosome coding (source: summarized by authors).

	GENE 1	GENE 2	GENE 3	GENE 4	...	GENE n
Customer number	v_1	v_2	v_3	v_4	...	v_t
Customer ID	s_1	s_2	s_3	s_4	...	s_t

$$0 < s_t < \mu_t + 2\sigma_t \, (t = 1, 2, 3, \ldots, I * J), \quad (12)$$

Step 2. Initialization of the Population. Add relaxation variables to equations (8)–(12) to convert into linear equations, figure out to get the basic solution system. Each point in the feasible set can be represented by a linear combination of basic solution systems, thereby generating multiple initial feasible solutions. Since s_t is an integer, the integer part of the obtained initial feasible solution is taken, thereby establishing an initial population composed of 50 feasible solutions. At the same time, the cross probability set in this paper is 0.6 and the mutation probability is 0.1.

Step 3. Calculation of Fitness. Since the objective function is a nonlinear function, it is difficult to analyze the function qualitatively. Therefore, the objective function is converted into a fitness function. Considering that the chromosome may exceed the feasible region after crossing and mutation, it can be constrained by constructing a fitness function with a penalty term. The fitness function is

$$\begin{aligned} f &= \max_s\left[E\left(\sum_{t=1}^{I*J} CTW_t\right)\right] + g, \\ g &= \begin{cases} 0, & if\ s_t \text{ is practicable} \\ 10^6, & \text{others} \end{cases} \end{aligned} \quad (13)$$

Step 4. Seed Selection. Use the roulette method to select the previous generation of individuals who enter the mating pool. Retain the best individuals of each subgroup and enter the mating pool directly. The other $n-1$ individuals are randomly selected using the roulette wheel algorithm to form a new generation mating pool group.

Step 5. Crossover and Mutation. The crossover operation uses a single-point crossover method, with each gene as a whole. Randomly select a gene on the chromosome, and cross the number of customer booking requirements. The mutation operation adopts the mutation method, that is, randomly select 2 positions of the chromosome and exchange the genes at the 2 positions to generate new chromosomes.

Step 6. Algorithm Termination. The genetic algorithm is an iterative search algorithm, which gradually approaches the optimal solution instead of obtaining the optimal solution through multiple evolutions. Therefore, it is necessary to determine the criteria for stopping operation. The termination condition used here is to specify the maximum number of iterations (the maximum number of iterations is 500). When the algorithm stops executing, the best individual in the history is designated as the result of the genetic algorithm.

6. Case Study

We take the service of AEU3 from COSCO Shipping Lines as an example. The service route rotation is shown in Figure 1 to be as follows: Tianjin-Dalian-Qingdao-Shanghai-Ningbo-Singapore-Piraeus-Rotterdam-Hamburg-Antwerp. The capacity and deadweight limitation is known as 18000TEU and 198000 ton per vessel correspondingly. We calculate the historical statistics in order to obtain the average demand, and cargo contribution of CMTX4 is calculated as it reflects all cost items. Table 5 presents the cargo contribution, average demand, standard deviation, and average weight of each service route segment. We study the allocation distribution so as to maximize the total cargo contribution.

Use the fitness functions $F = f = \max_{s} [E(\sum_{t=1}^{I*J} CTW_t)]$ and set the population size to 50, the maximum variation of the generation to 500, the probability of crossover to 50%, and the probability of mutation to 10%, and solve by MATLAB. The running time is 748 seconds after generation 501; the solution tends to be stable and reaches an approximate optimal solution as shown in Figure 5.

According to the genetic algorithm, the maximum payoff of the service route is \$4,139,400. Under this approximate optimal solution, Table 6 shows the allocation distributed in each segment.

7. Discussion

The above model solution shows that the rate of utilization of the entire service route reaches 100% while the rate of weight utilization reaches 99%. That is, the allocation distribution seems to best meet the requirements between the light and overweight cargo in different segments. The contribution for the whole service route is maximized by giving priority to high-contribution segments and high-contribution cargos. Thus, this seems to be an excellent solution to the container liner's YM. Thus, how is it possible to make an evaluation of the optimum solution in actual practice?

First, from the model solutions proposed by the genetic algorithm, one of the problems is the ignorance of the potential loss that will result from not satisfying the current customers' allocation requirements. The above solution might cause unexpected losses due to customer complaints. This could produce significant potential losses and significantly influence (in a negative way) the stability of the service route. Using the model solution, for example, looking at route numbers 2, 6, 8, 10, 21, 22, 23, and 24 under the approximate optimal solution of distribution strategy, only 2%, 5%, 55%, 0.4%, 2%, 1%, 40%, and 8%, respectively, of the average allocation demand have been matched. Such results could lead to severe customer complaints along with the potential loss of both customers and market share. These results, in turn, could cause unexpected losses that are not considered in the models and solution. A further solution in future research would be to add additional constraints (such as a deviation index) to ensure that maintenance and service stability are not affected. Another solution could be to conduct an evaluation of customers and divide them into different groups (such as global key accounts, regional key accounts, trade key accounts, big cargo owners, small and medium-size cargo owners, and spot-forwarding businesses) with further subdivision based on the average allocation demand in each segment. This can be done by calculating the different groups of customer requirements to determine the reasonable section of allocation distributed in each segment and adding the result into the mathematical model constraints.

Second, the model solution is based on the average demand of each segment and the segment's contribution analysis. This can be the benchmark when shipping carriers make decisions regarding each segment's allocation. However, the limitation with this strategy is the ignorance of each segment's allocation demand between the peak and slack seasons. These variations might significantly affect the contribution and the conclusion. For example, even when a certain segment's contribution is lower compared to others, the majority of the cargos remain in the slack season, and that segment's contribution cannot be simply evaluated by numbers. One possible solution is to add each segment's ratio between the average allocation demand to both slack and peak seasons. The ranking from high to low of such ratios should be considered when making decisions on the allocation distribution strategy (together with the contribution evaluation) and added as the mathematical model constraint.

Third, the model solution is based on the reconstruction of the contribution by maximizing the contribution of the service route. This can serve as the optimized strategy to achieve YM management objectives under a specific container liner's current customer structure and existing service route network. However, in actual YM practice, when container liners make decisions regarding their allocation strategies, all service routes in the network should be considered together with their competitors' service profile, both in general and in specific segments. This requirement relates to specific marketing strategies in specific areas and is an important factor in establishing competitiveness by virtue of a larger market share, better delivery times in certain markets, and superior service differentiation. This can be further studied through the game theory and by adding a segment competitiveness index in the mathematical model when deciding on a segment strategy.

Finally, the allocation distributed to each segment by the model solutions should be assigned to specific target customers. Because the different orders of some customers are often inseparable, no possibility exists to simply and strictly meet each segment's allocation. Doing so might cause potential losses due to booking shut outs that, in turn, could result if only a portion of the allocation is satisfied for different customers. How to adjust the allocations distributed in each segment and how to distribute allocations to each customer under contribution reconstruction using customer evaluations and allocation promises for long-term contracts should be studied further.

Table 5: Contribution and demand of ODF (source: summarized by the authors).

Loading port	Discharging port	CTW4	Average demand	Standard deviation	Average weight
Tianjin	Piraeus	$230	420 TEU	5	15Ton/TEU
	Rotterdam	$160	630 TEU	4	14Ton/TEU
	Hamburg	$260	520 TEU	6	15Ton/TEU
	Antwerp	$220	350 TEU	3	13Ton/TEU
Dalian	Piraeus	$220	120 TEU	5	14Ton/TEU
	Rotterdam	$145	150 TEU	4	13Ton/TEU
	Hamburg	$198	250 TEU	7	15Ton/TEU
	Antwerp	$176	160 TEU	4	14Ton/TEU
Qingdao	Piraeus	$265	460 TEU	3	13Ton/TEU
	Rotterdam	$154	750 TEU	6	12Ton/TEU
	Hamburg	$198	1340 TEU	2	14Ton/TEU
	Antwerp	$182	1650 TEU	6	13Ton/TEU
Shanghai	Piraeus	$275	1230 TEU	3	10Ton/TEU
	Rotterdam	$212	2450 TEU	5	9Ton/TEU
	Hamburg	$264	1980 TEU	4	11Ton/TEU
	Antwerp	$238	1940 TEU	6	10Ton/TEU
Ningbo	Piraeus	$263	920 TEU	5	11Ton/TEU
	Rotterdam	$207	1650 TEU	4	8Ton/TEU
	Hamburg	$258	1430 TEU	3	9Ton/TEU
	Antwerp	$236	1120 TEU	7	10Ton/TEU
Singapore	Piraeus	$164	360 TEU	2	9Ton/TEU
	Rotterdam	$152	540 TEU	4	11Ton/TEU
	Hamburg	$185	210 TEU	2	10Ton/TEU
	Antwerp	$176	120 TEU	3	10Ton/TEU

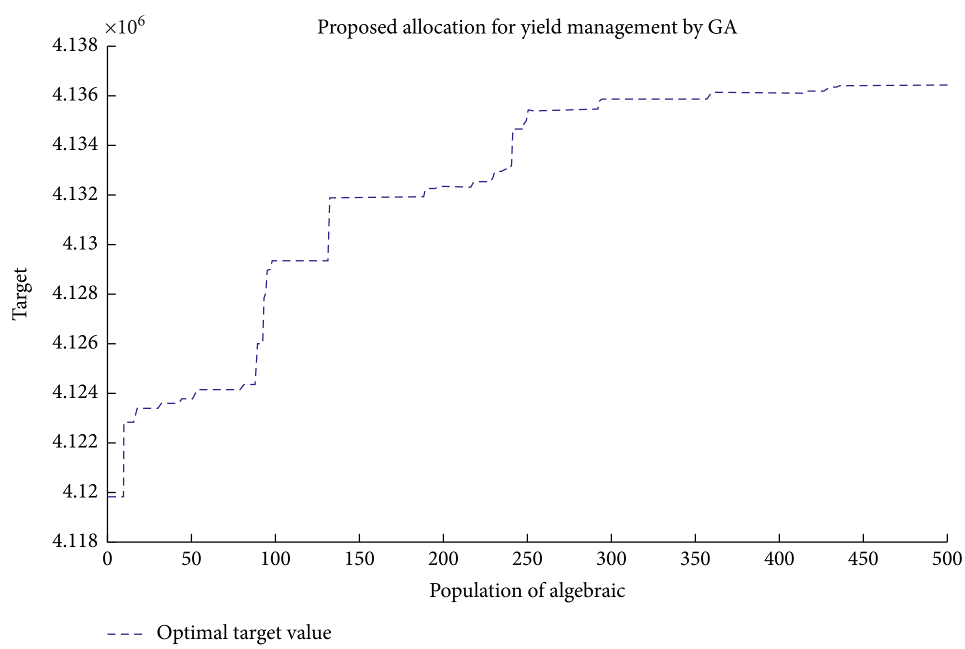

Figure 5: Convergence velocity of algorithm (source: drawn by the authors).

Table 6: Segment allocation proposed by MATLAB (source: summarized by the authors).

Loading port	Discharging port	Route number	f_t (CTW4)	Average demand	Standard deviation	Average weight	Allocation proposed
Tianjin	Piraeus	1	230.00	420	5	15	**430**
	Rotterdam	2	160.00	630	4	14	**15**
	Hamburg	3	260.00	520	6	15	**532**
	Antwerp	4	220.00	350	3	13	**356**
Dalian	Piraeus	5	220.00	120	5	14	**130**
	Rotterdam	6	145.00	150	4	13	**8**
	Hamburg	7	198.00	250	7	15	**235**
	Antwerp	8	176.00	160	4	14	**88**
Qingdao	Piraeus	9	265.00	460	3	13	**466**
	Rotterdam	10	154.00	750	6	12	**3**
	Hamburg	11	198.00	1340	2	14	**1319**
	Antwerp	12	182.00	1650	6	13	**1590**
Shanghai	Piraeus	13	275.00	1230	3	10	**1236**
	Rotterdam	14	212.00	2450	5	9	**2418**
	Hamburg	15	264.00	1980	4	11	**1988**
	Antwerp	16	238.00	1940	6	10	**1952**
Ningbo	Piraeus	17	263.00	920	5	11	**930**
	Rotterdam	18	207.00	1650	4	8	**1623**
	Hamburg	19	258.00	1430	5	9	**1440**
	Antwerp	20	236.00	1120	7	10	**1134**
Singapore	Piraeus	21	164.00	360	2	9	**7**
	Rotterdam	22	152.00	540	4	11	**6**
	Hamburg	23	185.00	210	2	10	**84**
	Antwerp	24	176.00	120	3	10	**10**

8. Conclusion

YM refers to the management of allocation and pricing to maximize the payoff in a stochastic environment. However, how to define the objectives is a matter worth discussing. The majority of the current research attributed the objective to maximizing revenue (e.g., total revenue and average revenue) without considering the generated relational cost. Other studies attributed the objective to profit maximization while costs were selected without considering how the costs were generated and calculated, or they were calculated repeatedly. The special characteristics of container liner shipping compared to air transport, hotel arrangements, or retail management must be reflected in the traditional YM models. This study proposes a new solution to evaluate the YM payoff by considering the special characteristics in container liner shipping. The idea is to reflect both cargo revenue and cost and to maximize the cargo contribution. All costs were identified and calculated according to the logic cost generated to allow evaluation of the cargo contribution. Although the number of plugs for reefers was not considered in the constraint, this will not affect the conclusions. It is common practice that container liners give priority to reefer containers and reserve allocation for reefer containers in advance. The reservation can be deducted from the whole capacity and will not lead to a different conclusion.

The emphasis of this study is to maximize the payoff though capacity management in different service route segments. Future proposed research directions would be the slot allocated to different customers in each segment and the pricing strategy and model solution based on the cargo contribution.

Data Availability

The datasets used during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Yisong Lin conceived and designed the analytic framework. Xuefeng Wang and Jian Gang Jin analysed the data. Yisong Lin wrote the paper. All the authors read and approved the final manuscript.

Acknowledgments

The author J. G. Jin is sponsored by the Shanghai Rising-Star Program.

References

[1] Q. Meng, H. Zhao, and Y. Wang, "Revenue management for container liner shipping services: critical review and future research directions," *Transportation Research Part E: Logistics and Transportation Review*, vol. 128, pp. 280–292, 2019.

[2] R. Hellermann, *Capacity Options for Revenue Management: Theory and Application in the Air Cargo Industry*, Springer Science & Business Media, Berlin, Germany, 2006.

[3] S.-C. Ting and G.-H. Tzeng, "An optimal containership slot allocation for liner shipping revenue management," *Maritime Policy & Management*, vol. 31, no. 3, pp. 199–211, 2004.

[4] L. R. Weatherford and S. E. Bodily, "A taxonomy and research overview of perishable-asset revenue management: yield management, overbooking, and pricing," *Operations Research*, vol. 40, no. 5, pp. 831–844, 1992.

[5] A. Gardon, P. Nielsen, and N. GormMalyRytter, *Challenges of Measuring Revenue, Margin and Yield Optimization in Container Shipping*, IFIP International Federation for Information Processing, Laxenburg, Austria, 2013.

[6] K. Littlewood, "Forecasting and control of passengers," in *Proceedings of the 12th AGIFORS Symposium Proceedings*, pp. 103–105, Nathanya, Israel, October 1972.

[7] T. C. Lee and M. Hersh, "A model for dynamic airline seat inventory control with multiple seat bookings," *Transportation Science*, vol. 27, no. 3, pp. 252–265, 1993.

[8] J. I. Mcgill, "Censored regression analysis of multiclass passenger demand data subject to joint capacity constraints," *Annals of Operations Research*, vol. 60, no. 1, pp. 209–240, 1995.

[9] L. W. Robinson, "Optimal and approximate control policies for airline booking with sequential nonmonotonic fare classes," *Operations Research*, vol. 43, no. 2, pp. 252–263, 1995.

[10] P. P. Belobaba and A. Farkas, "Yield management impacts on airline spill estimation," *Transportation Science*, vol. 33, no. 2, pp. 217–232, 1999.

[11] R. E. Chatwin, "Continuous-time airline overbooking with time-dependent fares and refunds," *Transportation Science*, vol. 33, no. 2, pp. 182–191, 1999.

[12] Y. Liang, "Solution to the continuous time dynamic yield management model," *Transportation Science*, vol. 33, no. 1, pp. 117–123, 1999.

[13] Y. Feng and G. Gallego, "Perishable asset revenue management with markovian time dependent demand intensities," *Management Science*, vol. 46, no. 7, pp. 941–956, 2000.

[14] Y. Feng and B. Xiao, "Optimal policies of yield management with multiple predetermined prices," *Operations Research*, vol. 48, 2000.

[15] G. Gallego and G. van Ryzin, "Optimal dynamic pricing of inventories with stochastic demand over finite horizons," *Management Science*, vol. 40, no. 8, pp. 999–1020, 1994.

[16] F. Glover, J. R. Glover, and C. McMillan, "The passenger-mix problem in the scheduled airlines," *Interfaces*, vol. 12, no. 3, pp. 73–80, 1982.

[17] P. P. Belobaba, "Survey paper-airline yield management an overview of seat inventory control," *Transportation Science*, vol. 21, no. 2, pp. 63–73, 1987.

[18] R. E. Curry, "Optimal airline seat allocation with fare classes nested by origins and destinations," *Transportation Science*, vol. 24, no. 3, pp. 193–204, 1990.

[19] S. L. Brumelle and J. I. Mcgill, "Airline seat allocation with multiple nested fare classes," *Operations Research*, vol. 41, no. 1, pp. 127–137, 1993.

[20] M. Brooks and K. J. Button, "Yield management: a phenomenon of the 1980s and 1990s?" *International Journal of Transport Economics*, vol. 21, no. 2, pp. 177–196, 1994.

[21] D. Ha, "Capacity management in the container shipping industry: the application of yield management techniques," Ph.D. thesis, The University of Tennessee, Knoxville, TN, USA, 1994.

[22] S. A. Maragos, "Yield management for the maritime industry," Ph.D. thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 1994.

[23] S. Zurheide and K. Fischer, "A revenue management slot allocation model for liner shipping networks," *Maritime Economics & Logistics*, vol. 14, no. 3, pp. 334–361, 2012.

[24] S. Zurheide and K. Fischer, "Revenue management methods for the liner shipping industry," *Flexible Services and Manufacturing Journal*, vol. 27, no. 2-3, pp. 200–223, 2015.

[25] Y. Wang, Q. Meng, and Y. Du, "Liner container seasonal shipping revenue management," *Transportation Research Part B: Methodological*, vol. 82, pp. 141–161, 2015.

[26] C. M. Feng and C. H. Chang, "Optimal slot allocation with empty container reposition problem for Asia ocean carriers," *International Journal of Shipping and Transport Logistics*, vol. 2, no. 1, pp. 22–43, 2010.

[27] L. H. Lee, E. P. Chew, and M. S. Sim, "A heuristic to solve a sea cargo revenue management problem," *OR Spectrum*, vol. 29, no. 1, pp. 123–136, 2006.

[28] H.-A. Lu and W.-H. Mu, "A slot reallocation model for containership schedule adjustment," *Maritime Policy & Management*, vol. 43, no. 1, pp. 136–157, 2016.

[29] D. Liu and H.-L. Yang, "Optimal slot control model of container sea-rail intermodal transport based on revenue management," *Procedia-Social and Behavioral Science*, vol. 96, pp. 50–59, 2013.

[30] UNCTAD, *Review of Maritime Transport 2008*, Tech. Rep., United Nations Conference in Trade and Development, Geneva, Switzerland, 2008.