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Liner Ship Freight Revenue and Fleet Deployment for Single Service

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Abstract. For single-liner ship service, this study optimizes containerized cargo revenue minus ship operating costs. The decisions to optimize the ship fleet and shipment plan are included in this proposed model. This optimization problem is formulated as a mixed-integer non-linear programming model and solved it using LINGO. The proposed model is applied to a liner service route provided in the computational study and the results are analyzed in case of different scenarios of container shipment demand and different freight rates.

Keywords: Liner ship, Freight Revenue, Fleet Deployment.

1 Introduction

Liner service is an efficient mode of marine freight transportation in which a ship owner sails the ship to a series of ports in sequential order. Each liner shipping company operates its own services along fixed routes with a set of ports of call. Containerized freight is mostly transported by liner ships on regularly scheduled service routes. Specific routes, specific ports, fixed ports of call and ship schedules, and fixed freight rates are among its four fixed characteristics. Liner shipping firms are mainly concerned with making a profit. To raise the shipping profit, the two most important aspects are reduction in operating cost and increasing freight revenue. Several fixed costs such as crew costs, repair and maintenance costs, marine insurance, stores, lubricant costs, and other major costs of fuel consumption, transshipment cost, berthing cost, loading and unloading cost altogether constitute the operating cost. The majority of freight revenue comes from the transportation of containerized cargo. Since freight rates vary between ports depending upon several types of cargo, the shipping plan selection has an impact on freight revenue. There is generally a high demand for cargo transportation, particularly during peak seasons, which makes determining the loading strategy more difficult. Existing studies on freight revenue maximization focus on several topics such as optimal itinerary selection for individual customer, cargo slot allocation, speed optimization, and ship deployment. For example, [1] developed a bi-level optimization model to solve the practical problem of deciding the optimal collection of itineraries to have for individual customers in order to optimize the expected profit. Next, [2] addressed a

slot allocation optimization model for a liner shipping network to take the right decisions on which containers to transport to maximize the company's profit. A liner seasonal service and freight revenue management problem is proposed to determine the number of different type of containers to assign to all ship routes, number of vessels deployed on the routes, and also the voyage speed of ships so that the total liner seasonal profit is maximized [3]. Different Revenue Management problems are investigated for liner shipping by analyzing supply, demand, customer segments, capacity control, pricing and RM decisions [4]. A mixed-integer non-linear non-convex programming model to plan itineraries of ports of call, employ vessels to visit the itineraries, and find the container shipping strategy with the vessels deployed to optimize overall benefit is developed and solved using a column generation based heuristic method [5]. An joint modeling approach is presented for the interconnected problems of liner ship deployment, network design, and empty repositioning [6]. An integrated mathematical model and matheuristic is proposed for the liner ship fleet deployment and repositioning problem to simultaneously determine the ships for each route and their corresponding moving cost to the assigned shipments [7].

Liner shipping company fulfils container shipment demand from longterm contracts as well as spot market. The problem of determining the optimal freight rate of spot containers between each origin port and destination port of a network in order to maximize overall profit is presented as a two-stage stochastic programming model [8]. The problem of container assignment that involves finding the optimal freight rates, number of container shipments and the transporting strategy for containers in a liner shipping network is proposed to optimize overall shipping profit [9]. Furthermore, the problems of finding optimal speed, refueling strategies, and shipment planning are also addressed in [10] with the objective of maximizing the cargo revenue minus bunkering cost for a single route. The number of containers loaded for each OD pair has a significant impact on the total profit. In this study, the freight revenue management problem focuses on two major decisions: fleet optimization and flow of containerized cargo between each origin-destination pair. Based on these two decisions, the profit of the manager is maximized. The problem formulated is a nonlinear mixed integer programming model and solved using LINGO.

The remainder of this paper is organized as follows: Section 2 provides the problem description and mathematical formulation of the problem. Applicability of the model and results are discussed in Section 3. Finally, section 4 provides the concluding remarks.

2 Problem Description

In most instances, a liner ship route's itinerary creates a loop, and a vessel deployed on the route can visit a port more than once. Let us take a liner route operated by a shipping company that covers a set of ports. For example, fig.1 presents a service route covering

eight ports. The number mentioned on the voyage legs of the route is the voyage length or the distance between two ports. Colombo and Salalah are visited twice in this shipping route by a vessel during its voyage. In practice, a shipping company typically employs the same type of vessels on the route to ensure weekly service frequency. If each port of call is visited once in a week by the vessels deployed on the service route, then the service frequency is weekly. Let I be the set of ports of call for the service route that implies it has $|I|$ number of ports of call and $|I|$ legs. Any port along the circular liner route can be called the origin port. The vessels depart from one port and returns to it after completing a round trip. The round-trip time is set because the liner ship route has specific schedules. All the ports of call have a fixed arrival time window for the deployed vessels. After arriving at the port, the vessel needs a port time including container handling time. The round-trip time includes both port operation and voyage time.

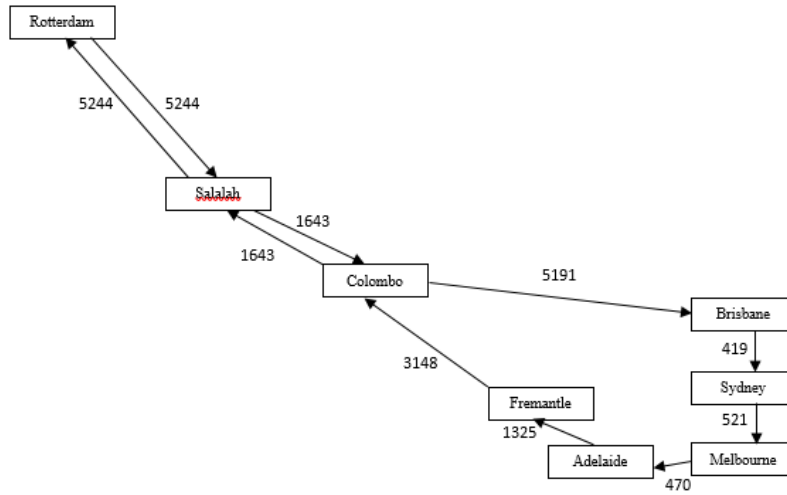


Fig. 1. Example of a liner service route with voyage length (nautical-miles).

We have considered the liner route with known voyage time for each leg, i.e., the vessel speed is fixed for all legs. On the liner ship route, every origin and destination port pair has a container shipping requirement weekly. Before the voyage, it is presumed that the number of containers to be shipped and the freight rate for each (O, D) port pair are given. It is also presumed that the shipping demand for each (O, D) port pair can be met in part. In most cases, the shipping company's ships are either chartered or their own ships. These ships are classified into various groups based on the loading capacity, berth occupancy fees, fixed operating costs, weight of the ships, and other ship-related characteristics. The aim of this study is to maximize the profit of the company considering the freight revenue and costs related to operating ships, fixed charges and berth occupancy charges for a liner ship service. The decisions to be taken here are to find the optimal fleet (type of ships and how many ships will be deployed) and the optimal quantity of containers to be loaded for each origin and destination pair.

2.1 Model Formulation

In this section, we present the mathematical model for the proposed profit maximization problem for a liner shipping company.

Model Parameters

The interpretations of the notations for sets, indices and parameters used here are mentioned below.

Sets:

| | |
|-----|----------------------|
| I | Set of port of calls |
| E | Set of vessels |

Indices:

| | |
|----------|------------------------|
| α | Index of port of calls |
| e | Index of vessels |

Parameters:

| | |
|-------------------|---|
| $K_{\alpha\beta}$ | Freight rate of transporting containers from α th port of call to β th port of call of the route |
| C_e^{opr} | Operating cost for vessel type e |
| C_e^{fix} | Fixed cost for vessel type e |
| C^{berth} | Berth occupancy charge |
| T | Average handling time of one TEU container |
| x_{min} | Minimum number of vessels deployed on the route |
| x_{max} | Maximum number of vessels deployed on the route |

Decision variables:

| | |
|-------------------|---|
| x | Required number of vessels deployed on the route |
| y_e | 1, if vessel type e is used 0, otherwise |
| $p_{\alpha\beta}$ | Number of containers loaded at α th port of call to be shipped to β th port of call of the route |
| q_α | Number of containers on the vessel when it arrives at port of call α (TEUs) |

Mixed-integer Non-linear Programming Model:

The objective function (1) is designed to maximize the profit of the shipping company. The first term in the objective function shown in equation (1) denotes the freight revenue of the shipping company achieved by transporting the containers from the origin ports to the destination ports according to the shipment demand. It also includes the operating costs for ships (second component), fixed costs related to ships (third component) and berth occupancy charge (fourth component). The mathematical model for the mixed integer non-linear programming is formulated as follows:

$$\text{Max} = \sum_{\alpha \in I} \sum_{\beta \in I} K_{\alpha\beta} p_{\alpha\beta} - \sum_{e \in E} x C_e^{opr} y_e - \sum_{e \in E} C_e^{fix} y_e - \sum_{\alpha \in I} TC_e^{berth} q_{\alpha} \quad (1)$$

Subject to

$$q_{\alpha} + \sum_{\beta \in I, \beta \neq \alpha} (p_{\alpha\beta} - p_{\beta\alpha}) = q_{\alpha+1} \quad \forall \alpha \in I \quad (2)$$

$$q_1 = \sum_{\substack{\alpha \in I \\ 2 \leq \alpha \leq m}} \sum_{\substack{\beta \in I \\ \beta < \alpha \\ 1 \leq \beta \leq m-1}} p_{\alpha\beta} \quad (3)$$

$$q_{m+1} = q_1 \quad (4)$$

$$0 \leq p_{\alpha\beta} \leq D_{\alpha\beta} \quad \forall \alpha, \beta \in I, \alpha \neq \beta \quad (5)$$

$$p_{\alpha\beta} \in \mathbb{Z} \quad \forall \alpha, \beta \in I, \alpha \neq \beta \quad (6)$$

Constraint (2) presents the relation between the total amount of containers loaded on a ship when it visits a port and the amount of containers for each origin and destination pair. Constraints (3) and (4) determine the total amount of containers loaded on a ship when it visits the first port of call during the round trip. Next, constraint (5) enforces that the quantity of loaded containers must not exceed the corresponding origin-destination shipment demand. Constraint (6) ensures that the loading quantity is a non-negative integer.

$$\sum_{e \in E} y_e = 1 \quad (7)$$

$$q_{\alpha} - \sum_{e \in E} Cap_e y_e \leq 0 \quad \forall \alpha \in I \quad (8)$$

$$168x \geq \sum_{\alpha \in I} (t_{\alpha} + Tq_{\alpha}) \quad (9)$$

$$x_{\min} \leq x \leq x_{\max} \quad (10)$$

Constraint (7) states that only one type of vessel can be deployed on the liner service route. Constraint (8) restricts that the number of containers on each leg should not exceed the capacity of the vessel deployed on the leg. Constraint (9) determines the number of ships required to be deployed on the route which lies in a range specified by the constraint (10). The problem formulated is a mixed-integer non-linear programming model and solved using LINGO.

3 Computational Study and Results:

In this section, the proposed modelling approach is applied to a liner service route containing four ports: Ho Chi Minh, Laem Chabang, Singapore, and Port Klang. The distance of the voyage lengths are 589, 755, 187, and 830 (in nautical miles) respectively

for all the legs. Hence, the liner service route has four ports of call. Let us consider that the ports have similar characteristics except for their location and the demand for containerized freight. Three vessel types are considered in this study based on the loading capacity, voyage related fixed costs and their operating costs (e.g., repair and maintenance cost). The capacities of the three type of vessels are 3000, 4500 and 6000 TEU respectively. The operating costs for the ships are 51923, 76923 and 115384 USD/week respectively. Similarly, the voyage related fixed costs are 219080, 282840, and 340000 USD. The average port handling time for the ships is 0.012 TEU/hour. The weekly container shipping demand (in TEUs) and container freight rate (USD/TEUs) for each origin-destination pair are provided in table 1.

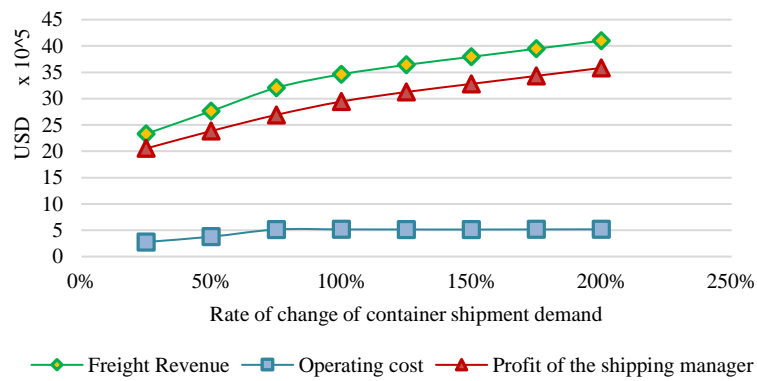
Table 1. Container shipment demand and Freight rates for each (O, D) pair.

| Origin-Destination Ports | Demand (TEUs) | Freight Rate (USD/TEUs) |
|---------------------------|---------------|-------------------------|
| Ho Chi Minh-Laem Chabang, | 897 | 477 |
| Ho Chi Minh-Singapore | 333 | 117 |
| Ho Chi Minh-Port Klang | 546 | 203 |
| Laem Chabang-Ho Chi Minh | 1332 | 376 |
| Laem Chabang-Singapore | 1026 | 187 |
| Laem Chabang-Port Klang | 1365 | 213 |
| Singapore-Ho Chi Minh | 813 | 271 |
| Singapore-Laem Chabang | 456 | 112 |
| Singapore-Port Klang | 858 | 266 |
| Port Klang-Ho Chi Minh | 417 | 407 |
| Port Klang-Laem Chabang | 573 | 164 |
| Port Klang-Singapore | 1118 | 458 |

While optimizing the fleet, the constraints (7) and (8) determine the type of the vessel needed to be deployed. Using the above data, the vessel type obtained is of capacity 6000 TEUs. Next, the constraints (9) and (10) find the required number of vessels. Hence, in this case two vessels of capacity 6000 TEUs are employed to visit all the ports. Constraints (2), (3), (5), and (6) help to find the amount of loaded containers to satisfy the demand for each origin and destination pair. In table 2, the optimal values of the number of containers loaded at α th port of call to be shipped to β th port of call of the route ($p_{\alpha\beta}$) are shown. Therefore, the flow of containers on the legs of the route are 3290, 5543, 4914 and 4253 TEUs respectively. Next, the container shipment demand for the origin-destination pairs are changed. If the container shipment demand increases, the change in the freight revenue, the operating costs and the total profit of the manager are represented in fig.2. Similarly, fig.3 represents the freight revenue, the operating costs and the total profit of the manager with respect to the increasing freight rate.

Table 2. Number of containers loaded and Freight rates for each (O, D) pair.

| Origin-Destination Ports | Number of containers loaded (TEUs) | Freight Rate (USD/TEUs) |
|--------------------------|------------------------------------|-------------------------|
| Ho Chi Minh-Laem Chabang | 897 | 477 |
| Ho Chi Minh-Singapore | 156 | 117 |
| Ho Chi Minh-Port Klang | 546 | 203 |
| Laem Chabang-Ho Chi Minh | 1332 | 376 |
| Laem Chabang-Singapore | 1026 | 187 |
| Laem Chabang-Port Klang | 1365 | 213 |
| Singapore-Ho Chi Minh | 813 | 271 |
| Singapore-Laem Chabang | 0 | 112 |
| Singapore-Port Klang | 858 | 266 |
| Port Klang-Ho Chi Minh | 417 | 407 |
| Port Klang-Laem Chabang | 573 | 164 |
| Port Klang-Singapore | 1118 | 458 |

**Fig. 2.** Change in freight revenue, operating costs and the total profit of the manager with respect to the increase in container shipment demand.

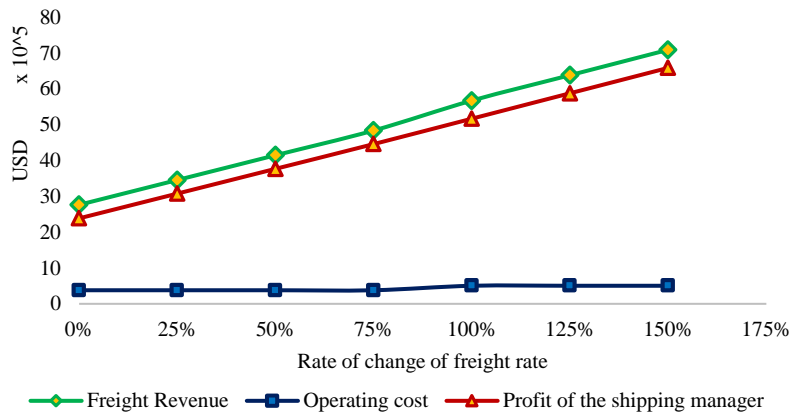


Fig. 3. Change in freight revenue, operating costs and the total profit of the manager with respect to the increase in freight rate.

4 Conclusion

This paper considers determining the ship fleet and container loading quantity jointly with the purpose of maximizing the freight shipping revenue while reducing the ship operating cost for one liner service. This optimization problem is formulated as a mixed-integer nonlinear programming model. For the computational study provided here, the proposed problem can be solved using LINGO. In conclusion, some discussions are made on the numerical results obtained for separate scenarios. We have shown if the container shipment demand increases, how the profit of the manager also increases. These observations may assist the shipping company in better understanding the consequences of various scenarios and making better liner service decisions.

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