THREE STUDIES ON
MARITIME OPERATIONS MANAGEMENT

GUO YU

MPhil

The Hong Kong Polytechnic University

2022

The Hong Kong Polytechnic University

Department of Logistics and Maritime Studies

THREE STUDIES ON MARITIME OPERATIONS MANAGEMENT

GUO Yu

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy

May 2022

Certificate of Originality

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgment has been made in the text.

_______________________________________(Signed)

_____________GUO Yu____________(Name of student)

Abstract

This thesis aims to address three critical issues in maritime operation. In the first study, a main problem of booking container slots in liner shipping is addressed. The shipper book container slots by an estimated demand, which may more or less than the actual demand, causing the mismatch problem and potential risk for carrier. This research proposed a Newsvendor model to address this issue with finding the optimal order quantity of container slots for the shipper. Moreover, this thesis suggests that the shipper should pay the reservation fee to the carrier because the uncertainties of container slots booking made by the shipper might cause revenue loss. Then, the study calculated the maximum profit by the optimal order quantity of the container slots. In the second study, most countries have banned the crew change during COVID-19, leading seafarers' working days extends their contract. This situation causes mental and physical diseases to seafarers. Therefore, opening ports for crew change is a way to solve the problem and is especially important during COVID-19. An integer linear programming (ILP) model is proposed to decide the number of opening ports while considering the cost of opening ports, the cost of crew change and penalty of unchanged crew members. Shipping transportation is mainly powered by heavy fuel oil and thus emits harmful emissions to the environment, such as particulate matter, hydrocarbons, carbon monoxide, and carbon dioxide (CO_2), causing negative effect to the environment and human health. IMO encourages shipping companies to use liquid natural gas (LNG) to replace the traditional fuels. LNG is a good source to be used in shipping transportation for its cleanness and easy storage. Bunkering is a necessary process if LNG is used. There are three common methods for LNG bunkering: ship-to-ship, truck-to-ship, and port-to-ship. The objective of this study is to find the optimal bunkering method to build in a port by adopting an integer liner programming (ILP) model and the objective of the ILP model includes three types of costs: fixed cost, variable cost, and extra cost. The results of the case study in this study demonstrate the effectiveness of the proposed model.

Keywords: Shipping operations management, container slots, Newsvendor model, ILP model, seafarer change, liquid natural gas, bunkering, clean energy

Acknowledgements

First, I would like to thank my supervisor, Dr. Shuaian (Hans) WANG. Dr Wang is easy-going, rigorous and attentive in his studies. Normally, he always explains detail information of the question that I am confused. Dr. Wang has profession insight and plenty new ideas in doing research. In terms of the writing and wording of the thesis, he will always teach me with patience about professional standards, starting from topic selection, topic setting, and repeated revision of the final thesis. Dr. Wang has always given me profound and meticulous guidance in a serious and responsible manner, helping me to develop research ideas, meticulously instructing and enthusiastic encouragement. For improving the personal ability, Dr. Wang always encourages me to attend the conference. Thanks to Dr. Wang's selfless help and enthusiastic encouragement, my graduation thesis can be successfully completed.

Second, I would like to express my deep gratitude to my father, mother, grandpa, and grandma, who took care of me growing up. They are always the first to encourage me when I am in trouble. Looking back on the road I have traveled over the past 20 years; every footprint is filled with their selfless care and earnest teachings. The 2 years of studying abroad have entrusted the ardent expectations of my family members for me. Their selfless support both spiritually and materially strengthened my belief in pursuing my ideal in life. Their love is the most selfless and generous love in the world. There is no way to repay the great kindness, but to be their proud with endless struggle and looking forward to a brilliant career in the future.

Third, Thanks to my classmate Zhang Silong. He is a very nice guy, always helps me when I am in trouble and teach me how to program by C++. Moreover, Zhang Silong has a flexible way of thinking about problems and a rigorous attitude in doing research. His solid professional knowledge and serious attitude of doing research have deeply influenced me and change my attitude of doing research. Then, I would like to thanks to my senior Yan Ran, a very nice, cute, and pretty girl. In the process of writing the thesis, I encountered difficulties and obstacles, some of which were overcome with the help of my senior Yan Ran. She always helps to revise the gramma of my paper and gives useful suggestions to me when I meet some problems of writing thesis.

Finally, I would also like to thank the monographs of the scholars cited in this paper. Without the inspiration and help of the research results of these scholars, I would not be able to complete the final writing of this paper. At this point, I would also like to thank my friends and classmates, who gave me a lot of useful materials in the process of writing my thesis and provided enthusiastic help in the typesetting and writing process of the thesis.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

The carrying capacity of seaborne ships is extremely large, which can reach hundreds of thousands of tons. Furthermore, the freight is relatively low compared with air transportation and road transportation. A ship has a large transportation volume, a long use time, and a long transportation mileage. Thus, more than 80% volume of cargo are transported by ships in global trade (UNCTD, 2021). There are two main modes of shipping transportation: Liner transportation means that cargo transported by container ships with fixed routes and schedules. Different from liner transportation, charter transportation's route and schedule are freely decided by the shipowner and the charterer. Our studies focus on linear shipping transportation.

From Alphaliner's latest data, the total container ships of operation are 6,344 in global transportation (Alphaliner TOP 100, 2022). The demand of container transportation is continually increasing after the outbreak of COVID-19, which shows that there is a huge demand of container liner shipping transportation.

Nowadays, the development of e-commence further promotes the development of shipping transportation. The outbreak of COVID-19 has changed the mode of shipping trade, promoting a new mode "online + offline". E-commerce platforms provide a chance for both parties (shipper and carrier) to digitalize the process, e.g., booking container slots by online platforms. Thus, the quantity of e-commerce platform that provide shipping service is increasing, e.g. Maersk Spot launched by Marske. More than 3000 shippers have ordered slots on Maersk Spot, and the ordered quantity increased from over 50,000 forty-foot-equivalent unit (FEU) in the second quarter of 2019 (Wagner, 2019) to 300,000 FEU in the fourth quarter of 2019 (Johnson, 2020). The huge demand of container transportation promotes the development of shipping and bring largely profit for the shipping companies. However, is also bring negative effect to the environment.

The environmental impacts of maritime transportation mainly include air pollution and water pollution. Ships are mainly powered by fossil fuel, emitting harmful emissions. For example, the shipping industry is responsible for around 940 million tons of carbon dioxide (CO_2) annually, which is at least 2.5% of the world's total CO_2 emissions (UK Research and Innovation, 2021). The emission of CO_2 is estimated to increase without further control measures.

The prosperity development of shipping transportation brings many other problems and some of them can be optimized. Hence, we conduct three research to optimize maritime operation problems, which are about maximizing the carrier profit, guaranteeing seafarers' benefit, and realizing green transportation.

In the research of booking container slots, how to maximize the carrier profit of booking container slots has been focused by the shipping companies in liner shipping industry. In liner transportation, cargo is transported by container with fixed routes and schedules. Hence, a shipper must book container slots before the schedule of ship's departure time if a shipper has demand to transport his/her cargo via E-platform. However, the number of container slots that will be booked is an estimated demand, leading the mismatch between actual demand and booked container slots. Meanwhile, the shipper can cancel the booked container slots without any punishment, causing the revenue loss of carrier due to wasted ship carrying capacity. Hence, how to maximize the profit is important for carrier and how to find the optimal booking container slots is equally important for the shipper. To guarantee the carrier's profit, we propose that the shipper should pay reservation fee that is not refundable when booking the container slots. Meanwhile, in this study, we use a newsvendor model to find the optimal booking container slots for the shipper. Under the optimal booking container slots, we will find the maximum profit for the carrier.

In the part of seafarers' benefit, the outbreak of COVID-19 has taken huge risk to seafarers change. Seafarer change has been banned by most countries, causing working long time out of the contact. This situation takes largely pressure to seafarers, even causing physical and mental diseases e.g., fatigue and sleep deprivation. Hence, it is an urgent need to solve the crew change problem during COVID-19. International

Maritime Organization (IMO) encourages governments to open ports for crew change. Therefore, we build an Integer Linear Programming (ILP) model to find the optimal set of ports for crew change.

In the aspect of environment, the global shipping transportation activities emit around 940 million tons of carbon dioxide (CO_2) annually, which is at least 2.5% of the world's total CO_2 emissions (UK Research and Innovation, 2021). It takes huge burden to environment and brings negative effect on people healthy. Thus, using natural gas to reduce emission is an important method to reduce harmful emissions. Liquid natural gas (LNG) is encouraged to be used instead of the traditional fuel, as LNG is cleaner, and less emission intensive compared with the traditional fuel. For ships using LNG as a fuel, LNG bunkering is an unavoidable process. There are many methods to bunker LNG fuel to ships. In this study, we discuss three modes to bunker LNG ships, which are truck-to-ship (TTS), ship-to-ship (STS), port-to-ship (PTS). The three modes have different advantages and limitations. Hence, in this study we build an ILP model to find the suitable method for a port to choose for bunkering LNG fueled ships.

The three problems are widely focused by shipping companies, government, and society. In the study of booking container slots, we use newsvendor model to find the optimal order quantity of container slots and then optimize the carrier's profit, which is a solution beneficial to both parties. In the study of crew change, ILP model is proposed to decide the set of opening ports for crew change. Finally, in the study of LNG bunkering infrastructure planning, a complex ILP model is built to find of the optimal bunkering methods of LNG fuel to ships. More importantly, the solutions of these studies can be suggestions to the government and industry and promote the development of our society.

Chapter 2. Maximizing profit of booking container slots[1]

2.1 INTRODUCTION

Maritime transportation, which plays an important role in international trade, has two main operating modes: liner and charter. Liner transportation is a service of transporting goods, mostly containerized goods (containers), by ships with regular routes and fixed schedules. In contrast, ships involved in charter transportation do not have pre-established sailing routes and schedules as well as ports of call. This study aims to analyze the optimal order quantity of container slots within the context of liner shipping.

According to the data published by Alphaliner in August 2021, 6,254 container ships are in operation globally, with a total capacity of 24,938,712 twenty-foot equivalent units (TEUs) (Alphaliner TOP 100, 2021), which shows that there is a huge demand of container liner shipping transportation. Before actual transportation of goods, container slots booking is a main step. Slots on a container ship can be booked through an e-commerce platform. Several weeks before a voyage of a liner ship, its company, which is also called a carrier, will open the available container slots on that liner ship for online booking. If a shipper wants to transport his/her cargo to the destination port using liner shipping services, it first needs to contact the liner shipping company to book container slots through the e-commerce platform based on the estimated demand. Next, the shipping company accepts the booking and asks customer (i.e., shipper) to pack the cargo into the containers and deliver them to the container yard. Finally, the containers are loaded onto the liner ship and transported to the destination port.

Nowadays, e-commerce has provided an alternative way to launch shipping services, even in the relatively traditional maritime industry. For example, China has successfully used e-commerce in shipping and trade services to reduce delivery time

[1] Guo, Y., Yan, R., Wang, H. (2021). Maximization of container slot booking profits for carriers in the liner shipping industry. Journal of Shipping and Trade, 6(1), 1-10.

(Panova et.al., 2019). A series of shipping e-commerce platforms have also emerged in the shipping market. For example, Maersk launched its online ordering channel of container slots called Maersk Spot. More than 3000 shippers ordered slots on Maersk Spot, and the ordered quantity increased from over 50,000 forty-foot-equivalent units (FEUs) in the second quarter of 2019 (Wagner, 2019) to 300,000 FEU in the fourth quarter of 2019 (Johnson,2020). Moreover, the "Internet + shipping" provides a new way to book container slots online, where liner shipping companies are trying to explore online sales channels to sell container slots (Lam and Zhang, 2019). The development of 5G networks is expected to further enhance the efficiency of e-commerce platforms. In the liner shipping industry, Hu et al. (2019) has proved total revenue of liner company under the e-commerce environment is greater than under the traditional environment e-commerce by the model of maximizing the revenue of liner company, which enables the traditional paper-based booking system to evolve into a more advanced online booking system. Two advantages can be offered by e-commerce platforms. First, shippers can efficiently access the newest available container slot information via the internet and make container booking plans according to their needs. Second, liner companies are able to obtain the up-to-date container reservation information and make corresponding adjustments in time. Thus, booking container slots online is beneficial to both shippers and carriers.

One problem in the booking process is that the number of slots ordered by shippers is based on estimation in most cases. However, the actual demand is uncertain as many factors, e.g., market environment and natural conditions, can impact the demand. As a result, the actual demand and the ordered quantity of containers may not match. More specifically, there are three cases of the demand uncertainty faced by a shipper. In the first case, the number of booked slots exceeds the actual demand; as a result, the shipper will cancel some slots. In the second case, the number of booked slots equals the actual demand. In the third case, the booked slots are fewer than the actual demand.

Consequently, the uncertainty brings risks to the carrier because the un-utilized container slots fail to generate revenue and thus cause revenue loss. Therefore, carriers should adopt a strategy to guarantee their profits. In this study, we assume that a shipper is required to pay a reservation fee when booking container slots and the remaining container fee will be paid after the cargo has been unloaded at the departure port. In other words, the reservation fee will become part of the transportation fee if the shipper successfully transports the estimated amount of cargo to the destination port. Meanwhile, the reservation fee will be non-refundable if the shipper cancels some or all the booked container slots.

2.2 LITERATURE REVIEW

Research papers of maximizing the carrier's profit from container slots booking can be divided into two streams. One stream is focused on slot allocation, which is related to inventory control in revenue management. For example, Pei et al. (2007) developed a slot allocation model and proposed a method to calculate the allocation of containers according to different characteristics of ports and ships. Wang et al. (2021) proposed a two-stage stochastic mixed-integer nonlinear programming model to address the slot allocation problem. Mao and Shen (2016) proposed a probability scheme-based slot allocation model for vehicular networks. Feng and Xiao (2006) developed a comprehensive decision support model to integrate decisions on pricing and allocation of container slots' capacity. They found that the optimal decision was influenced by price, and strength of demand. Peng et al. (2017) proposed hybrid scheduling mechanisms that integrated the advantages of both distributed and centralized scheduling mechanisms. Lee et al. (2007) claimed that selling slots to the right customer with the right price at the right time could generate the maximum benefit for a liner company. Feng and Chang (2010) formulated a mathematical programming model to maximize the operational profit of slot allocation for ocean carriers, subject to constraints of vessel capacity, container demand, and empty container supply. Guo et al. (2018) established a stochastic allocation model considering the multiple dimensions of container type, size, deadweight tonnage, and capacity. This model was then combined with long-term contractual customer booking requirements and the randomness of supply and demand.

In practice, many factors can influence the demand for container slots in the shipping industry. Nevertheless, shippers book container slots based on the estimated demand in most cases, causing a possible mismatch between the actual and estimated container demands. As a result, shippers must cancel some or book more slots from the shipping market at a higher price. Therefore, another stream of container slot research is focused on the overbooking of container slots and analyzes the problem of container slot cancellation. For example, Wang et al. (2007) calculated the maximum expected profit and focused on the problem of overbooking in liner shipping. Later, Wang and Meng (2019) proposed three different forecasting models, i.e., a piecewise linear regression model, an autoregressive model, and an artificial neural network model, to predict the canceled quantities of container slots by mining container slot booking patterns from historical booking data. Unfortunately, due to the lack of real-time data, the up-to-date characteristics and patterns of container slot booking cancellation given the current shipping market conditions remain unclear. Zhao et al. (2019) proposed a conceptual model to analyze container slot cancellation in intercontinental shipping services between Asia and the US West Coast. Zhao et. al. (2020) further considered the primary factors influencing container slot cancellation to estimate the cancellation probability in long-haul transport in liner shipping services.

There are few existing studies aiming to determine the optimal number of container slots that a shipper should book. In the shipping market, booked container slots can be canceled for free, causing revenue loss to the carrier. In contrast, in the airline market, a customer pays a high cancellation fee if it cancels a booked seat due to personal reasons. Potentially, carriers can use a similar strategy to decrease the cancellation rate. Therefore, this study aims to determine the optimal order quantity of container slots for the shipper and the maximum profit for the carrier.

2.3 MODEL

We use q to denote a shipper's real demand where q is a random variable and has a uniform distribution in (0, 1). We use x to denote the booked slots, and x is a decision variable for the shipper and has a uniform distribution in (0, 1). The shipper's demand is unknown; therefore, there are three cases of the actual and the booked quantity of container slots presented as follows.

(a) If $q < x$, the shipper books more container slots from the carrier than it really needs. Thus, the shipper needs to cancel $q - x$ slots. Note that the reservation fee is non-refundable in this case.

(b) If $q = x$, the number of booked slots matches the actual demand. As this case is rare in practice because the numbers of q and x are several tens or even several hundreds, we do not consider it in this study.

(c) If $q > x$, the shipper books fewer container slots from the carrier than it really needs. Therefore, the shipper needs to obtain $x - q$ more slots from the shipping market. In order to transport the cargo to the destination port on time, the shipper needs to find container slots in a limited time, and such urgent demand leads to the growth of the container slot booking fee as a consequence. Thus, the market price for a slot is higher than the price provided by the carrier (Sofreight, 2020).

We further define some parameters to calculate the shipper's cost. We use θ (USD) to represent the reservation fee of each slot booked. We assume that the transportation fee of each container slot is α (USD) offered by the carrier and $\alpha > \theta$, and the market price of each slot is β (USD). As the price for the x container slots are decided by both the carrier and the shipper and is lower than the market price, we have $\beta > \alpha$. Therefore, a shipper's cost includes two parts, the reservation fee and transportation fee.

We start by calculating the cost of the shipper in the first case where $x > q$. In this case, the shipper books more container slots than the actual demand and the carrier only transports q containers. Therefore, the total cost of the shipper includes the transportation fee for q container slots and the reservation fee for $x - q$ container slots.

We denote by C_1 the total cost in the first case. The objective function can be formulated as follows:

$$C_1 = \alpha q + \theta(x - q). \quad (2.1)$$

We then calculate the shipper's cost in the case where $x < q$, which means that the shipper needs to book $q - x$ more container slots from the shipping market with price β. We denote by C_3 the total cost of the shipper in this case, and the total cost can be formulated as follows:

$$C_3 = \alpha x + \beta(q - x). \tag{2.2}$$

2.3.1 The shipper's optimal order quantity

The problem of finding a shipper's optimal order quantity is an instance of the newsvendor problem. The newsvendor or newsboy problem, also called a single-period inventory management problem, is an inventory management model that seeks to identify an optimal order quantity to maximize the expected profit in a period (Khouja, 1999; Qin et al., 2011). The key insights stemming from the analysis of this newsvendor problem have a broad range of application in managing inventory decisions in many industries, such as hospitality, airline, and fashion goods. Therefore, this study applies the newsvendor model to determine the optimal order quantity of container slots for a shipper.

At the beginning of a single period, the shipper is interested in determining the optimal order quantity of container slots, denoted by x^*. The shipper's booking demand is assumed to be stochastic and characterized by a random variable x with the probability density function as $f(x)$ and the cumulative distribution function as $F(x)$. The carrier is assumed to operate with sufficient capacity and no capacity restrictions and zero lead time of supply. Therefore, the order placed by the shipper from the carrier at the beginning of a period is immediately fulfilled. The sales of the container slots occur during or at the end of a period. Thus, the actual cost at the end of the period for the shipper is

$$C = \begin{cases} \alpha q + \theta(x - q), q < x; \\ \alpha x + \beta(q - x), q > x. \end{cases} \tag{2.3}$$

As the demand is not realized at the beginning of the period, the shipper cannot observe the actual cost. Hence, a normal approach to analyzing the problem is to allow the shipper to make the optimal decision on ordering quantity at the beginning of the period to maximize the carrier's expected total profit. Thus, the total expected profit for the carrier can be formulated as follows:

$$E(C) = \int_0^x [\alpha q + \theta(x - q)] f(q) dq + \int_x^1 [\alpha x + \beta(q - x)] f(q) dq$$

$$= \theta x + \beta + (\beta - \alpha + \theta) \int_0^x q\, f(q) dq + (\beta - \alpha + \theta) \int_x^1 x\, f(q) dq. \tag{2.4}$$

Next, by calculating the partial derivative of the expected profit for x, we obtain

$$\frac{\partial E(C)}{\partial \theta} = \theta + (\beta - \alpha + \theta) \left[x f(x) + \int_x^1 f(q)\, dq + x f(x) \right]$$

$$= \theta + (\beta - \alpha + \theta)(1 - x). \tag{2.5}$$

Therefore, by setting $\partial E(C)/\partial \theta = 0$, we can obtain the optimal order quantity x^* as follow:

$$x^* = \frac{\beta - \alpha}{\beta - \alpha + \theta}. \tag{2.6}$$

2.3.2 The carrier's maximum profit

In this study, we assume that the carrier's marginal cost is 0, and thus the carrier's profit equals the shipper's cost. We denote P by the carrier's profit. As we have found the optimal order quantity x^*, we can use x^* to substitute the carrier's profit function. Accordingly, we have

$$P = \begin{cases} \alpha q + \theta(x^* - q), q < x^*; \\ \alpha x^*, q > x^*. \end{cases} \tag{2.7}$$

We need to find the optimal values of θ and α to maximize the carrier's profit. In doing so, we first find the carrier's expected profit denoted by $E(P)$. Next, we can obtain the objective function as follows

$$E(P) = \int_0^{x^*} [\alpha q + \theta(x^* - q)] dq + \int_{x^*}^1 \alpha x^*\, dq$$

$$= \alpha x^* - \frac{1}{2}(\alpha - \theta) {x^*}^2$$

$$= \frac{\beta - \alpha}{2(\beta - \alpha + \theta)^2} [\alpha(\beta - \alpha) + \theta(\alpha + \beta)]. \tag{2.8}$$

Next, we calculate the partial derivative of the expected profit for θ as follows

$$\frac{\partial E(P)}{\partial \theta} = \frac{(\beta^2 - \alpha^2)(\beta - \alpha + \theta)^2 - 2(\beta - \alpha + \theta)(\beta - \alpha)[\alpha(\beta - \alpha) + \theta(\alpha + \beta)]}{(\beta - \alpha + \theta)^2}. \tag{2.9}$$

The optimal θ^* can be found when $\partial E(P)/\partial \theta$ = 0, and we have the following equation under this condition

$$(\beta^2 - \alpha^2)(\beta - \alpha + \theta)^2 = 2(\beta - \alpha + \theta)(\beta - \alpha)[\alpha(\beta - \alpha) + \theta(\alpha + \beta)]. \tag{2.10}$$

After solving Eq. (10), we have

$$\theta^* = \beta - \alpha - \frac{2\alpha(\beta-\alpha)}{\alpha+\beta}. \tag{2.11}$$

2.4 SENSITIVE ANALYSIS

In this study, parameters such as the reservation fee, the price of container slots offered by the carrier, and the market price of container slots fluctuate in practice. In this section, we discuss how the reservation fee decided by the carrier and the expected profit of the carrier can be influenced by changing these parameters. Hence, we conduct a sensitive analysis in this section. Sensitivity analysis is to find out the sensitive factors (e.g., the price of container slots offered by the carrier, and the market price of container slots) that have an important impact on the indicators (e.g., optimal booking quantity for the shipper and expected profit for the carrier), and then analyze and calculate the degree of influence and sensitivity on the indicators of the project by changing the value of sensitive factors. Therefore, people can judge the risk tolerance of the project from the results of sensitive analysis. However, there is a main shortcoming of sensitive analysis. Sensitive analysis cannot determine the true range of a certain uncertainty factor and the probability of change within this range, which leads certain risks to the shipper and the carrier.

We first discuss how the reservation fee (θ) can be influenced by changing a container slot's price offered by the carrier (α). We assume that the market price (β) is equal to 1000 USD and set α in the range of $(0.9\beta, \beta)$. The results are plotted in Figure 2-1 It can be seen that the optimal reservation fee decreases and converges to 0 when the value of α increases and converges to β. The managerial insight generated for carriers is that a lower reservation fee should be set if the difference between α and β is smaller.

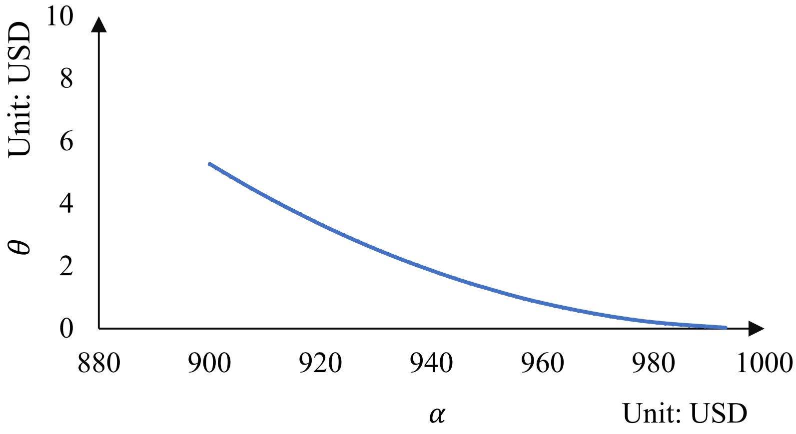


Figure 2-1: Optimal reservation fee under different values of α

Next, we analyze the impact of the price of one container slot offered by the carrier (α) on the optimal order quantity x^* for the shipper. We also set the market price (β) at 1000 USD and change α from 900 USD to 1000 USD and the results are shown in Figure 2-2 It indicates that the optimal order quantity of container slots increases when the price of one container slot offered by the carrier increases. This may be counterintuitive at first sight. However, a closer examination of Figure 2-1 indicates that when the price of one container slot offered by the carrier increases, the reservation fee decreases, and their joint effect leads to the increase of the optimal order quantity.

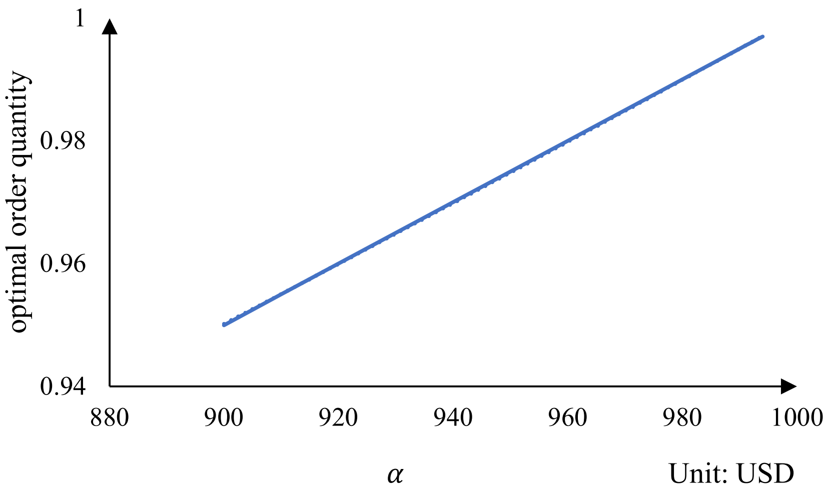


Figure 2-2: Optimal order quantity under different values of α

Finally, we consider how the expected profit of the carrier would be influenced by increasing the price of a slot offered by the carrier and the results are shown in Figure 2-3 It can be seen that the carrier can obtain more profit when the value of α increases.

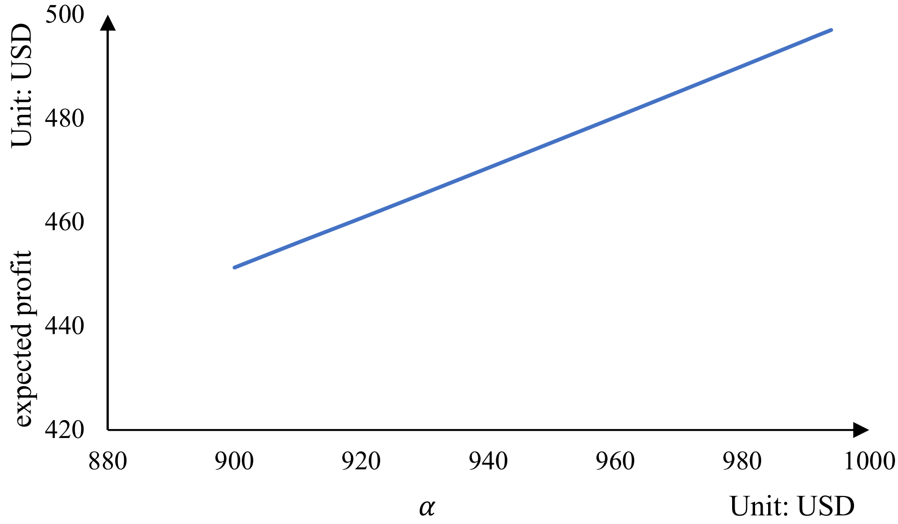


Figure 2-3: Expected profit under different values of α

2.5 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This study makes the first attempt to solve the uncertainty problem in container slots booking that causes risk to the shipper and the revenue loss to the carrier. We first propose a newsvendor problem to find the optimal order quantity of container slots for the shipper. We then calculate the carrier's maximum profit under the shipper's optimal order quantity of container slots. However, most parameters we consider fluctuate in practice. Hence, we assume that the market price is fixed and then discuss its impact on the reservation fee, the optimal order quantity, and the expected profit by increasing the price of one container slot offered by the carrier. This study can help to manage and promote the online container booking systems in the liner shipping industry.

Future studies will focus on the following aspects. First, this paper assumes that the carrier has sufficient capacity. However, there are many factors, e.g., the COVID-19, affecting the capacity of the carrier in actual liner shipping services. As a result, the capacity of container slots might be insufficient, which yields two cases of booking container slots for the shipper. The booked container slots of the shipper are equal or less than carrier's capacity. And affected by the market factors, there still exists the uncertainty between booked container slots and actual demand. Under this situation, finding the optimal order quantity of container slots, not extending carrier's capacity, is of highly significance for the shipper. Hence, future research can consider the optimal order quantity of the shipper under insufficient capacity of container slots.

Second, only one shipper is considered in this paper. As many shippers have the demand of container slots from the shipping market, future research can consider more complex situations with one carrier and more shippers to find the maximum expected profit for the carrier considering the shippers' decisions. In the situation with one carrier and more shippers, we can consider two cases to calculate the maximum expected profit for the carrier. The first case is that the whole capacity of container slots has been booked by those shippers. The second case is that there exists surplus of carrier's capacity. Under the two different conditions, we should calculate carrier's expected profit. Based on this calculation, optimization models for maximizing carrier's expected profit should be developed.

Chapter 3. Ports Opening Optimization for Crew Change in COVID-19[2]

3.1 INTRODUCTION

Shipping is the backbone of international trade. The United Nations Conference on Trade and Development (UNCTAD, 2021) estimated that the annual global volume of seaborne shipments in 2020 was at 10.6 billion tons. To keep the global economy running, especially in difficult circumstances such as the COVID-19 pandemic, it is vital to keep ships sailing and goods, especially medical supplies and food, moving.

At sea, the global merchant fleet is operated by 1.65 million seafarers. Seafarers are required to sign long-term contracts with shipping companies that specify the length of period spent onboard, which is usually weeks or months; thus, they stay at sea for long periods of time and endure separation from home and society (Carotenuto et al., 2012). Seafaring is a highly stressful profession (Oldenburg et al., 2010), and seafarers are prone to both physical and mental exhaustion (Oldenburg et al., 2012; Hystad and Eid, 2016). Because they experience many stressors, such as separation from family, loneliness, cross-cultural miscommunication, fatigue and sleep deprivation, physical problems, lack of recreation, workplace noise, ship movement, vibration, and heat (Oldenburg et al., 2013; Jepsen et al., 2015).

Crew changes are therefore essential for the functioning of international shipping. Normally, every month, approximately 100,000 seafarers disembark from the ships that they operate to comply with regulations governing safe working hours and crew welfare, and are replaced by others (The conversation, 2020). Crew change keeps global trade moving smoothly. However, because countries have tightened their borders in response to the spread of COVID-19, seafarers are prohibited from boarding or leaving ships at most ports, and many remain on their vessels after their contracted shifts. Given that

[2] Guo, Y., Yan, R., Wu, Y., Wang, H. (2022). Ports Opening for Seafarer Change during the COVID-19: Models and Applications. Sustainability, 14(5), 2908.

more than a quarter of seafarers suffer from depression (Safety4Sea, 2018), banning crew changes would further put their mental health at risk (De Beukelaer, 2021), increasing the likelihood of marine accidents, jeopardizing global supply chains, and ultimately exacerbating current hardships.

Some authorities have attempted to alleviate the obstacles of crew changes. For example, the U.K. and Jamaica have categorized seafarer change as an essential service (itfseafarers, 2020; The Maritime Executive, 2020). And Singapore have allowed the seafarers whose contract has expired to change (Seatrade, 2020). Ports in Canada have remained open for crew changes (Seaman, 2020). Moreover, the International Maritime Organization (IMO) and the European Commission have called on governments to coordinate efforts to designate ports for crew changes (BIMCO, 2021). IMO and Doumbia-Henry, C. (2020) proposed that the safety of crew change should be ensured (IMO, 2020).

Research in this area has focused on seafarers' physical and mental stress and the shortage of seafarers. These problems have become more severe during the COVID-19 pandemic. Crew members are exposed for months on end to high levels of physical and mental stress (Oldenburg and Jensen, 2012). Strained family relationships and social isolation are considered the major antecedents of perceived stress (Iversen, 2012). Researchers from Cardiff University (Lefkowitz and Slade, 2019) surveyed 1,856 seafarers and found that they experienced significant job-related stress and suffered as a result of excessive working hours (often more than 12 hours a day), a situation hidden by an alarming number of falsified records. Over 40% of seafarers reported disturbed sleep, mainly due to noise and motion.

Seafarers' job-related stress is a major cause of maritime accidents (Kim and Jang, 2016) and burnout (Chung et al., 2017). An Australian team summarized the maritime accident data from 1960 to 2009 and reported that more than 9,000 seafarers had committed suicide or disappeared at sea during this period. This suggests that seafarers have poor mental health, which can have fatal consequences (Smith et al., 2016). The result was echoed by research conducted by a team at Yale University in 2019, which showed that 20% of seafarers had either considered or attempted suicide (Lefkowitz and Slade, 2019). Because of chronic physical and mental fatigue, overwork, and isolation from family and friends, seafarers decide to leave their jobs, and the industry has found it difficult to attract enough new employees to make up the shortfall. The International Chamber of Shipping forecasted on the global supply of and demand for seafarers, which foresaw a future shortage of seafarers (INTERNATIONAL LABOUR ORGANIZATION, 2019).

The IMO reported that during the COVID-19 pandemic, more than 100,000 seafarers stayed at sea for months beyond the end of their contracts (Sohu, 2021). This situation has caused great mental stress, fatigue, and exhaustion to seafarers, increasing the risk associated with sailing. Crew change is an important part for ensuring the physical and mental health of the seafarers. Due to the difficulties in changing crew during the epidemic, their psychological condition is worsened. Therefore, we propose to use an integer linear programming (ILP) model to solve the problem of opening ports to help crew change, which is beneficial to their physical and mental health. ILP model means that the variables in the plan (all or part) are restricted to integers. If in a linear model, the variables are restricted to integers, it is called integer linear programming.

3.2 PROBLEM DESCRIPTION

Opening ports will induce different kinds of costs, such as port management costs and quarantine costs, amongst others. Hence, we mainly consider the costs of a port opening for crew change as the key factor. A mathematical model to minimize the total cost of opening ports and crew change penalties is presented in this section. A penalty means that the shipowner needs to pay extra costs to the seafarer, per day, if the current total working days of the seafarer extend past the contract (10 months). The measure of a penalty can prevent seafarers from continuing to work out of the contract and benefit crew change. A set of ports, P, indexed by $p \in \{1, 2, \dots, |P|\}$, is available to serve a set of ships, S, indexed by $s \in \{1, 2, \dots, |S|\}$. The ports are assumed to be discrete and able to handle the ships' docking. Assume that each ship docks at a port once and t_{sp} is the arrival time of ship s to port p. Here, Δ_{sp} is set to 1 if ship s docks at port p during a planning horizon, and 0 otherwise. The total number of crew members on ship s is denoted as M_s. We use $m \in \{1, 2, \ldots, M_s\}$ to index the crew members on ship s. The number of days that crew member m has worked is τ_{ms}. We assume that the period of a crew member's contract, e.g., 10 months, is γ, and that a new crew member will not disembark during a planning horizon.

The objective function of this problem includes the cost of one change in seafarers (α), the penalty (d) per day for a crew working beyond the contracted period, and the cost (C) for opening a port. Hence, we need to find the minimum sum of the total costs of opening a port/ports and crew changes, and the penalties.

3.3 MODEL SETUP

We address the problem of minimizing the crew change cost and penalty described in Section 2 by developing an ILP model. The following assumptions are made as part of the proposed formulations.

(1) There is no interruption during crew change activities;

(2) The ports that allow crew change can be opened immediately by the government when the total social cost is minimized;

(3) The duration of the contracts of all crew members is identical (e.g., 10 months);

(4) During the planning horizon, each ship docks at the port once and is allowed to change one crew;

(5) The cost of opening a port for crew change is identical for all regions. The cost of a crew change is also the same for all ships. In addition, the penalty for each crew is the same.

The notation used in this study is defined as follows.

Indices, sets, and parameters

P set of ports, $p \in \{1, 2, \ldots, |P|\}$;

S set of ships, $s \in \{1, 2, \ldots, |S|\}$;

γ duration of a crew's contract;

M_s number of all crew members;

τ_{ms} number of days that crew m has worked on ship s;

t_{sp} arrival time of ship s at port p;

T duration of a planning horizon, e.g., 365 days;

α cost of changing a crew;

d penalty per day for each crew working beyond the contract;

C cost of opening a port;

Δ_{sp} parameter that equals 1 if ship s docks at port p during a planning horizon, and 0 otherwise.

Decision variables

The x_p decision variable is set to 1 if port p is open to allow seafarer changes at the beginning of the planning horizon; otherwise, it is set to 0;

The y_{spm} decision variable is set to 1 if crew member m is changed when ship s docks at port p; otherwise, it is set to 0.

Furthermore, we denote C_T as the total cost based on the above definitions of the parameters and decision variables. Finally, the ILP model is formulated as follows:

$$Min\ C_T = \sum_{p\in P} Cx_p + \sum_{s\in S}\sum_{m=1}^{M_s}\{\sum_{p\in P} y_{spm}\big[\alpha + d\max\big(t_{sp} + \tau_{ms} - \gamma,\ 0\big) + d\max\ (T - t_{sp} - \gamma,\ 0)\big] + (1 - \sum_{p\in P} y_{spm}) d\max(\tau_{ms} + T - \gamma, 0)\} \quad (1)$$

subject to

$$\sum_{p\in P} x_p \geq 1 \quad (2)$$

$$y_{spm} \leq x_p \quad \forall s \in S, \forall p \in P, \forall m \in \{1, 2, \dots, M_s\} \quad (3)$$

$$y_{spm} \leq \Delta_{sp} \quad \forall s \in S, \forall p \in P, \forall m \in \{1, 2, \dots, M_s\} \quad (4)$$

$$\sum_{p\in P} y_{spm} \leq 1 \quad \forall s \in S, \forall m \in \{1, 2, \dots, M_s\} \quad (5)$$

$$x_p \in \{0,1\} \quad \forall p \in P \quad (6)$$

$$y_{spm} \in \{0,1\} \quad \forall s \in S, \forall p \in P, \forall m \in \{1, 2, \dots, M_s\}. \quad (7)$$

Objective Function (1) minimizes the sum of the costs of opening ports and crew change and the penalty of staying beyond the contract. Specifically, the term $\alpha + d\max\big(t_{sp} + \tau_{ms} - \gamma, 0\big) + d\max\ (T - t_{sp} - \gamma, 0)$ is the crew change related cost if crew m on ship s is changed at port p. In addition, α is the cost of a crew change, $d\max\big(t_{sp} + \tau_{ms} - \gamma, 0\big)$ is the penalty for an existing crew member working beyond the contract, and d max $(T - t_{sp} - \gamma, 0)$ is the penalty for a new crew member working beyond the contract. Moreover, term $d\max(\tau_{ms} + T - \gamma, 0)$ is the crew change related cost if crew m on ship s is not changed during the planning horizon, which is the penalty for an existing crew member working beyond the contract. Constraint (2) ensures that at least one port is open for crew change. Constraint (4) ensures that a crew can be changed when ship s docks in port p. Constraint (5) states that at most one crew member can disembark from ship s in a port. Finally, constraints (6) and (7) guarantee the domain of the decision variables.

3.4 NUMERICAL EXPERIMENTS

To evaluate the proposed model, we perform several computational experiments using a PC (Intel Core i7; memory, 16 GB, Mountain View, CA, USA). The mathematical model proposed in this study is coded in $C^{\#}$ and implemented by CPLEX 12.6.2. CPLEX is a mathematical optimization technique, which is used to increase efficiency, implement strategies quickly, and increase profitability.

3.4.1. Performance of the Model

We first summarize our parameter settings. The planning horizon is 365 days. The contract of each crew member is 300 days. As mentioned above, the cost in the objective function includes three parts: opening ports, crew change, and the penalty. The cost of the crew change for each crew member is USD 4000, which is in line with maritime news [15]. There is a penalty if the crew member's working days extend beyond the contract, and this penalty is assumed to be USD 100 for one crew member per day. Data on working days for each crew member, routes for each ship, and the dock time for each ship are randomly generated.

Several numerical experiments considering scenarios with different numbers of ship routes are carried out to validate the proposed model. Table 3-1 lists the results provided directly by CPLEX. The number of ports include total ports, and the number of routes represents different schemes of docking ports, which means that ships docks at different ports among the total ports. We consider the same number of ports on different routes in a single instance. CPU time represents the running time for each instance in seconds. We find that the CPU running time increases in different instances with the same number of ports: as the number of routes increases, so does the CPU running time.

Table 3-1: Results provided by CPLEX

Instance No	Number of ports	Number of routes	CPU Time(s)
1	5	5	143
2	5	10	186
3	5	15	202
4	5	20	218
5	10	5	189
6	10	10	226
7	10	15	278
8	10	20	312
9	15	5	214
10	15	10	264
11	15	15	316
12	15	20	350

3.4.2 Sensitive Analysis

In this section, we discuss how the cost of opening ports can influence the number of open ports, the number of crew changes, the penalty, the cost of crew changes, and the total cost. To achieve this goal, we use Instance 1 with five total ports and five different routes to conduct a sensitivity analysis. In this instance, the parameters (the number of total ships, the days worked, the total number of crew members, the penalty for each crew member working beyond the contract's end, and the cost for each crew change) are identical. We want to find the influence on total cost, the number of open ports, the penalty, and the number of crew changes by changing the cost of opening a port.

We first discuss the relationship between the cost of opening a port and the number of open ports by increasing the cost of opening ports. The results presented in Figure 3-1 indicate that cost of opening ports and the number of open ports is negatively correlated. We find that the number of open ports that permit a crew change decreases from three to one when the cost of opening port increases to USD 500,000 (but not to zero because we require that at least one port be open for crew change). Only one port opens for crew change when the cost increases from USD 500,000 to USD 600,000.

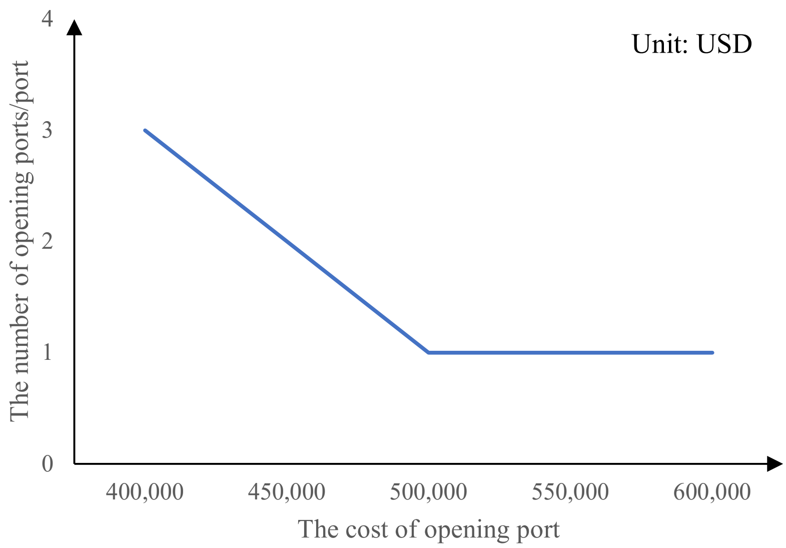


Figure 3-1： The number of open ports as the cost of opening port increases

Next, we discuss the relationship between the cost of opening ports and the crew change penalty. The results presented in Figure 3-2 indicate that the penalty increases when fewer ports are open for crew changes. Furthermore, it indicates that crew change priority is given to crews whose days worked go beyond the contract. Hence, the penalty is smaller when three ports are open for crew changes.

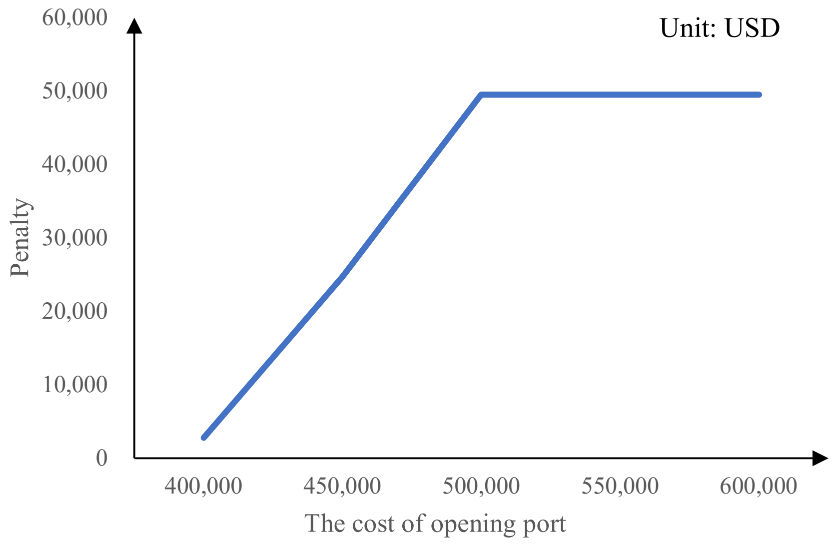


Figure 3-2: The penalty as the cost of opening port increases.

Next, we want to find the relationship between the cost of opening ports and the cost of crew changes. It can be seen from Figure 3.3 that the cost of crew changes decreases as the cost of opening a port increase. From the results in Figure 3-2, we can conclude that fewer crews can be changed when fewer ports are open for crew changes.

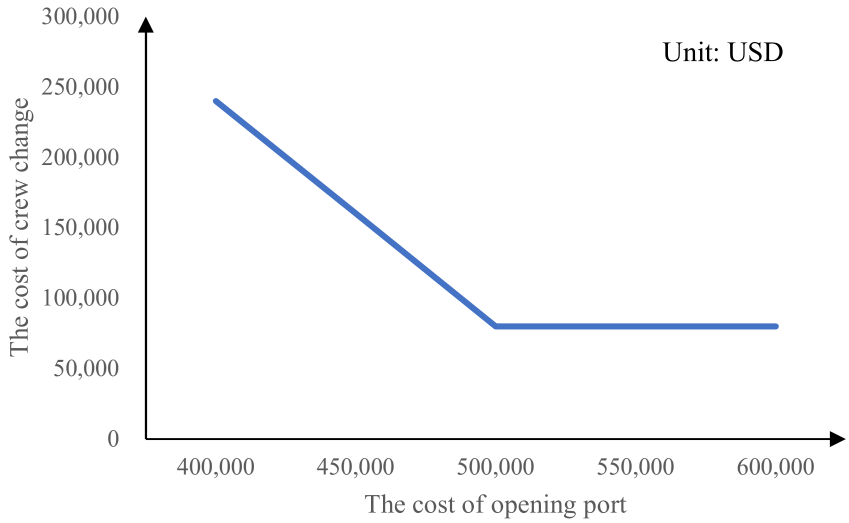


Figure 3-3: The cost of crew changes as the cost of opening port increases.

Finally, we want to find how the total cost reflects increases in the cost of opening a port. As the results plotted in Table 2 show, the total cost increases from USD 627,400 to USD 917,200 as the cost of opening a port increases from USD 400,000 to USD 500,000. It is also interesting to find that the total cost increases slowly after USD

500,000. This is because, as discussed above, we require that at least one port to be open for crew change, and the cost increases from USD 500,000 to USD 600,000. As the penalty cost and the cost of crew change remain unchanged when the cost of opening a port increases from USD 500,000 to USD 600,000, the total cost increases more slowly after USD 500,000.

Table 3-2: The total cost as the cost of opening port increase

Case No.	The cost of opening a port	The total cost
1	400000USD	627400USD
2	450000USD	777000USD
3	500000USD	917200USD
4	550000USD	967200USD
5	600000USD	1017200USD

3.4.3 Discussion

In this section, we use an instance that is calculated by CPLEX to find how the cost of opening ports can influence the number of open ports, the number of crew changes, the penalty, the cost of crew changes, and the total cost. However, there are some limitations.

First, the instance might not be sufficient to conclude all cases in normal shipping activities because we need to consider more parameters in reality, e.g., ship delay costs. Thus, in future research, more parameters should be considered in this model. Second, the scale of crew changes and ports opening might be larger than the model proposed for shipping activities during the normal period. However, due to the lack of the real data, the data used in numerical experiments are assumed within a certain range, including the current working days of crew members, the penalty and the routes of the ships. The results of the model can provide some suggestions based on the assumed data. Hence, it can be expected that we would obtain more reliable conclusions after gaining the real data in the future research.

3.5 CONCLUSIONS

Shipping is the most cost-effective way to transport large volumes of goods over long distances. To keep the global economy running, it is vital to keep ships sailing during the COVID-19 pandemic. Every month, around 100,000 seafarers need to disembark from the ships that they operate to comply with regulations governing safe working hours and crew welfare, and then another 100,000 seafarers embark. However, seafarers are prohibited from boarding or leaving ships at most ports because of COVID-19 restrictions, which increases seafarers' stress and fatigue. This problem cannot be fully addressed unless autonomous ships are prevalent in the world.

This study aims to solve the problem of seafarers' crew change. We propose an ILP model by considering three components: opening ports, crew change, and penalty. We propose 12 instances for the ILP model solved by CPLEX, which demonstrates the computational efficiency of our model.

Lastly, we conduct a sensitivity analysis by choosing one instance to discuss how the cost of opening a port can influence the number of open ports, the number of crew changes, the penalty, the cost of crew changes, and the total cost. We find that the number of ports open for crew changes and the cost of crew changes decrease when the cost of opening ports increases. The penalty and total cost increase when the cost of opening ports increases. It can thus be concluded that, when the cost of opening a port is high, the risks associated with crew change will increase because fewer ports will be open for crew changes.

We believe the study has positive impacts on two aspects: seafarers and society. Seafarers are vulnerable to epidemics. It is difficult for them to receive immediate medical treatment once they contract an epidemic at sea. Most seafarers must disembark at foreign ports. However, during the epidemic, many countries close their borders. Thus, seafarers must stay at sea far beyond the contract period and do not know when they can return home. Considering that, under normal circumstances, seafarers have to work in an isolated environment for months and suffer from stress, anxiety and depression, banning them from disembarking will be detrimental to their mental health. This study can solve the problem of mental health and is beneficial to seafarers.

For society, crew changes will enable them to maintain world trade and strengthen the global response to epidemics. Shipping is the most cost effective way to transport large quantities of goods over long distances. More than 80% of global trade is transported by sea, including food, medical supplies, energy, raw materials and finished products. Some production activities are stopped during epidemics to prevent the spread of diseases. Then, shipping plays a more important role in maintaining global supply chains and providing basic food and medical supplies to many countries. Therefore, facilitating crew change can ensure normal shipping activities.

Chapter 4. LNG bunkering infrastructure planning at port

4.1 INTRODUCTION

In the global trade, more than 80% of the volume of cargos are transported by ships (UNCTAD, 2018). With the advancement in globalization, cargo transportation demand is constantly growing, resulting in an increase in the number of ships sailing around the world. Fossil fuel is the major type of energy consumed by ships, and thus the demand of fuel energy consumed by ocean-going vessels also increases. Meanwhile, ships emit harmful emissions to the environment as a result of fossil fuel consumption. Such emissions include particulate matter, hydrocarbons, carbon monoxide, and carbon dioxide (CO_2).

794m tons of CO_2 were emitted in 2020 during shipping activities, and there was an increase rate at 4.9% to 833m tons in 2021 (Lloyd's List, 2022). The emission of CO_2 brings negative effects to the environment and the health of human beings. To be more specific, from the perspective of environment, the greatest harmful effect of excessive CO_2 emissions is the greenhouse effect. The increasing greenhouse effect will lead to global warming, resulting in a series of unpredictable global climate problems, e.g., rising surface temperatures, melting glaciers, and rising sea levels. Furthermore, the increasing CO_2 levels in the atmosphere causes an imbalance in the climate system and increase the number of heatwaves, which can lead to more forest fires. From the perspective of the health of human beings, the main adverse impact of CO_2 is to stimulate the human respiratory center, resulting in shortness of breath, and can cause headaches, confusion, and other symptoms. A rapid breathing is to inhale a lot of oxygen under high concentration of CO_2, but too rapid breathing can affect the gas exchange in the lungs, further aggravating the problem of hypoxia. In such a vicious circle, patients with CO_2 poisoning will fall into a coma for a short period of time. By considering the two aspects, using a cleaner source of fuel to reduce the emission of CO_2 is widely concerned by the global government.

Natural gas is a kind of environment-friendly fuel, compared with other traditional fuels e.g., oil, coal, and propane, which emit less harmful emissions. For example, about 117 pounds of CO_2 are produced per million British thermal units (MMBtu) equivalent of natural gas compared with more than 200 pounds of CO_2 per MMBtu of coal and more than 160 pounds per MMBtu of distillate fuel oil (EIA, 2021). Thus, natural gas is encouraged to be adopted in the shipping industry as an alternative fuel to replace the traditional fuels.

Liquid natural gas (LNG) is a kind of natural gas in liquid form under normal pressure after purifying the natural gas produced in the gas field and a series of ultra-low temperature liquefaction. LNG is a good resource to power shipping activities, as compared with other types of natural gas such as compressed natural gas (CNC) which is pressurized and stored in a container in a gaseous state, LNG takes up less storage space. Furthermore, LNG is more suitable for long distance transportation than CNC. This makes LNG a common fuel choice for many shipping companies.

For ships using LNG as fuel, LNG bunkering is necessary. There are many methods to bunker LNG onto ships. In this study, we focus on three modes to bunker LNG ships, which are truck-to-ship (TTS), ship-to-ship (STS), and port-to-ship (PTS). The detailed information of the three modes is shown in Table 1. Especially, typical volume (V) represents the quantity of LNG fuel in cubic meter that can be stored by one truck/ship/port. Bunker rates (Q) show how much LNG can be bunkered from a truck/ship/port to a ship in one hour. As the three modes have different advantages and disadvantages. this study aims to find a suitable mode of LNG bunkering for a given port.

Table 4-1: Introduction and comparison of LNG bunkering methods

Method	Typical Volume (V) and Bunker Rates (Q)	Advantages	Disadvantages
TTS: The LNG bunkering truck is usually connected to the receiving vessel on the dock using a flexible hose.	$V \approx 50 - 100\ m^3$ $Q \approx 40 - 60\ m^3/h$	• Flexible operation. • Low infrastructure requirements. • Adaptive to different safety requirements. • Serving different LNG users on point-to point delivery.	• Limited capacity. • Limited movement on the terminal side. • Roadside restrictions (e.g. traffic restrictions).
STS: LNG is delivered by another ship or barge to the receiving ship.	$V \approx 100 - 6500\ m^3$ $Q \approx 500 - 1000\ m^3/h$	• Not interfering with cargo operations. • The most adaptable LNG bunkering mode. • Larger delivery volume and higher efficiency.	• High initial investment cost. • The size of bunkering vessels is limited by ports.
PTS: LNG can be directly filled from small LNG storage units and small bunkering stations.	$V \approx 500 - 20000\ m^3$ $Q \approx 1000 - 2000\ m^3/h$	• Faster deliveries and higher quantities. • A good choice for ports with long-term bunkering needs.	• Difficult to get LNG receiving ships to berth to bunkering terminals. • Availability is hard to be guaranteed in large LNG terminals. • Difficult to estimate the amount of LNG available for bunkering in small storage tanks.

4.2 LITERATURE REVIEW

Several previous studies have provided insight into the development of LNG bunkering management problems: bunkering network setting and bunkering station. The bunkering network setting related the site selection issues and bunkering network planning. Some researchers are interested in the bunkering network setting. Kim et.al. (2021) adopted an empirical analysis approach as selection criteria for shipping companies' selection of an LNG bunkering port. Zhao et.al. (2022) considered five aspects which include natural, infrastructure, economic, safety and policy factors to constructs a comprehensive evaluation system for the site selection of LNG bunkering stations. Wang (2014) calculated the results of single ship berth bunkering capacity to propose a bunkering network planning of Chongqing LNG bunkering port. Ursavas et.al. (2020) discussed the network design by considering a multi-period capacitated demand capturing network design model with the bunkering method of pipeline and TTS.

There have been many studies that analyze the risk, e.g., leakage, fire and explosion, associated with LNG bunkering. Davies and Fort (2014) developed a risk assessment model to find the release likelihood of LNG fuel. Elsayed et al. (2009) proposed a semi-quantitative risk assessment approach for LNG gas carriers during loading/offloading at terminals. Iannaccone et al. (2020) applied quantitative risk assessment approach to determine the risk levels pertinent during LNG bunkering process. Xuan et.al. (2019) studied the risk based on the dynamic model during LNG fueling process. Arnet (2014) applied a quantitative risk assessment to assess the risk in LNG bunkering operations. Jeong et al. (2017) showed that the high level of explosion risk was related to high pressure of LNG gas. Fan et al. (2022) applied a dynamic quantitative risk assessment methodology to analyze dynamic risks during LNG bunkering. Xie et al. (2022) found that heat radiation is the main threat causing leakage risk by quantitative risk assessment model.

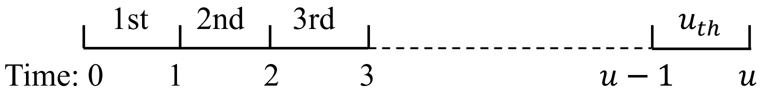
In the stream of bunkering station, most researchers focus on the safety zone settling. Safety is one of the most important factors in LNG bunkering because LNG is a cryogenic liquid stored in insulted tanks. LNG may release from part of the stored tanks and thus lead to potential threats such as asphyxiation, cryogenic burns, fires and even explosions when the leaked gas meets a source of ignition (Crowl and Louvar, 2001). Moreover, these accidents may trigger lager chain accidents in LNG bunkering station (IMO, 2015). Therefore, some literature focuses on the safety management in LNG bunkering station. Skramstad (2013) presented the progress of guidance on how to meet safety requirements in the LNG bunkering. Jeong et al. (2017) conducted a statistical method under a computer build program to determine the safe zone in LNG bunkering station. Park et al. (2018) found that wind speed, wind direction, ship geometry and loading condition affected the extent of safety zones by computational fluid dynamics simulations in a specific case. Park and Paik (2022) proposed a hybrid method to design the safety zone during LNG bunkering by the method of truck-to-ships.

Although many studies have discussed the bunkering network design, bunkering station and safety zone settling, only few studies have discussed which kind of LNG bunkering method is the optimal method at a port. For example, Lee et al. (2021) conducted analytic hierarchy process analysis to find the optimal method of bunkering LNG, which indicated that the optimal method is STS, then followed TTS and PTS. Yu et.al. (2021) calculated a geometric aggregation by considering four factors, which are assessment of LNG supply for ships, suitability of fuel supply, risk of spillage, and domestic and international standards. The result indicated that STS was the optimal method in Busan port. In this study, we take a different perspective to find the optimal bunkering method by considering the bunker rate and the cost of bunkering LNG fuel.

4.3 MODEL SETUP

The three methods of bunkering LNG fuel to ship have advantages and limitations. Hence, we want to explore what kinds of bunkering LNG fuel to ship should be constructed in a port. In this section, we develop an Integer Linear Programming model to address the problem. The following assumptions are made as a part of the proposed formulations.

1) There is no interruption during bunkering activities.
2) Only one method is used to bunker LNG fuel to a ship when the ship docks at port. The number of trucks/ships that bunker LNG fuel to the ship remains unchanged throughout the bunkering process.
3) The start time of bunkering LNG fuel to a ship must be no earlier than the ship's arrival time to the port.
4) The expected departure time for a ship could beyond the end time of bunkering.
5) Time is a moment on the timeline, e.g. 1, 2 and 3 as shown in the following figure. Time interval indicates the length of time, e.g. 1st, 2nd and 3rd. The u_{th} hour is a time interval, which is from time $u-1$ to time $u.$



The notation used in this study is defined as follows.

Parameters:

C_T The purchase cost of a truck (Unit: USD);

C_S The purchase cost of a ship (Unit: USD);

C_P The cost of building a port which is able to bunker LNG fuel to ships (Unit: USD);

α A conversion factors that can convert the total cost into hourly cost;

αC_T The per hour cost of purchasing a truck (Unit: USD);

αC_S The per hour cost of purchasing a ship (Unit: USD);

αC_P The per hour cost of building a port of bunkering (Unit: USD);

c_T Variable cost for per truck to bunker a ship (Unit: USD);

c_S Variable cost for per ship to bunker a ship (Unit: USD);

c_P Variable cost for the port to bunker a ship (Unit: USD);

N_T The maximum number of trucks that bunker a ship at the same time;

N_S The maximum number of ships that bunker a ship at the same time;

q_T The hourly volume of bunkering a ship by a truck (Unit: m^3);

q_S The hourly volume of bunkering a ship by a ship (Unit: m^3);

q_P The hourly volume of bunkering a ship by the port (Unit: m^3);

W A set that LNG-fueled ships dock at the port;

t_{w1} Arrival time of ship w;

t_{w2} Expected departure time of ship w (The period of ship w docks at port is from t_{w1} to t_{w2}, which means that the planed time of docking at port is $t_{w2} - t_{w1}$);

G_w The quantity of LNG fuel for ship w to bunker (Unit: m^3);

p_w Extra cost if actual departure time extends planning time because of bunkering (Unit: \$/hour)

U: The set of hours in the planning horizon (Unit: hours)

M: A larger number, which is defined in following constraints.

Decision variables

y_{wT} A decision variable that is set to 1 if the ship is bunkered LNG fuel by a truck/trucks; otherwise, it is set at 0;

y_{wS} A decision variable that is set to 1 if the ship is bunkered LNG fuel by a ship/ships; otherwise, it is set at 0;

y_{wP} A decision variable that is set to 1 if the ship is bunkered LNG fuel by the port; otherwise, it is set at 0;

x_{wT} The number of trucks used to bunker ship w;

x_{wS} The quantity of ships used to bunker ship w;

z_T A non-negative integer, which is the number of purchased LNG trucks for bunkering;

z_S A non-negative integer, which is the number of purchased LNG bunkering ships;

z_P A binary variable that is set to 1 if the PTS should be constructed; otherwise, it is set at 0;

γ_{wuT} The number of trucks to bunker ship w in the u_{th} hour;

γ_{wuS} The number of ships to bunker ship w in the u_{th} hour;

γ_{wuP} A binary variable that is set to 1 if ship w is bunkered by PTS in the u_{th} hour;

τ_{w1} The start time to bunker ship w;

τ_{w2} The end time to bunker ship w. The overall bunkering period for ship w is $\tau_{w1} - \tau_{w2}$;

Δ_{wu} A decision variable that is set to 1 if the beginning time of bunkering ship w is u; otherwise, it is set at 0;

Δ_{wu} A decision variable that is set to 1 if the end time of bunkering ship is u; otherwise, it is set at 0;

π_{wu} A decision variable that is set to 1 if ship is bunkering in u; otherwise, it is set at 0.

Furthermore, we denote C by the total cost. Based on the above definitions of parameters and decision variables, the ILP model is formulated as follows:

$$Min\ C = \alpha C_T z_T + \alpha C_S z_s + \alpha C_p z_p + \sum_{w \in W} (c_T x_{wT} + c_s x_{ws} + c_P y_{wP})$$
$$+ \sum_{w \in W} p_w \max(0, \tau_{w2} - t_{w2}) \quad (1)$$

subject to

$$y_{wT} + y_{wS} + y_{wP} = 1, w \in W \quad (2)$$

$$x_{wT} \leq M y_{wT}, w \in W \quad (3)$$

$$x_{wS} \leq M y_{wS}, w \in W \quad (4)$$

$$x_{wT} \leq N_T, w \in W \quad (5)$$

$$x_{ws} \leq N_S\ w \in W \quad (6)$$

$$M(1 - y_{wT}) + q_T \sum_{u \in U} \gamma_{wuT} \geq G_w, w \in W \quad (7)$$

$$M(1 - y_{wS}) + q_S \sum_{u \in U} \gamma_{wuS} \geq G_w, w \in W \quad (8)$$

$$M(1 - y_{wP}) + q_P \sum_{u \in U} \gamma_{wup} \geq G_w, w \in W \quad (9)$$

$$\tau_{w1} \geq t_{w1}, w \in W \quad (10)$$

$$\sum_{u \in U} \Delta_{wu1} = 1, w \in W \quad (11)$$

$$\tau_{w1} = \sum_{u \in U} u \Delta_{wu} \ \ , w \in W \quad (12)$$

$$\sum_{u \in U} \Delta_{wu2} = 1, w \in W \quad (13)$$

$$\tau_{w2} = \sum_{u \in U} u \Delta_{wu2}, w \in W \quad (14)$$

$$\pi_{wu} \leq \sum_{u'=1}^{u-1} \Delta_{wu'1}, u = 1, 2, 3, \dots, U \quad (15)$$

$$\pi_{wu} \leq \sum_{u'=u}^{U} \Delta_{wu'2}, u = 1, 2, 3, \dots, U \quad (16)$$

$$\pi_{wu} \geq \sum_{u'=1}^{u-1} \Delta_{wu'1} + \sum_{u'=u}^{U} \Delta_{wu'2}, u = 1, 2, 3, \dots, U \quad (17)$$

$$M(\pi_{wu} - 1) + x_{wT} \leq \gamma_{wuT} \leq M(1 - \pi_{wu}) + x_{wT}, w \in W, u = 1, 2, 3, \dots, U \quad (18)$$

$$M(\pi_{wu} - 1) + x_{wS} \leq \gamma_{wuS} \leq M(1 - \pi_{wu}) + x_{wS}, w \in W, u = 1, 2, 3, \dots, U \quad (19)$$

$$M(\pi_{wu} - 1) + y_{wP} \leq \gamma_{wuP} \leq M(1 - \pi_{wu}) + y_{wP}, w \in W, u = 1, 2, 3, \dots, U \quad (20)$$

$$\sum_{w \in W} \gamma_{wuT} \leq z_T, u = 1, 2, 3, \dots, U \quad (21)$$

$$\sum_{w \in W} \gamma_{wuS} \leq z_S, u = 1, 2, 3, \dots, U \quad (22)$$

$$\gamma_{wuP} \leq z_P, u = 1, 2, 3, \dots, U \quad (23)$$

$$z_P \in (0, 1) \quad (24)$$

$$\gamma_{wuP} \in \{0, 1\}, u = 1, 2, 3, \dots, U \quad (25)$$

$$y_{wT} \in \{0, 1\}, w = 1, 2, 3, \dots, W \quad (26)$$

$$y_{wS} \in \{0, 1\}, w = 1, 2, 3, \dots, W \tag{27}$$

$$y_{wP} \in \{0, 1\}, w = 1, 2, 3, \dots, W \tag{28}$$

$$\Delta_{wu1} \in \{0, 1\},\ u = 1, 2, 3, \dots, U \tag{29}$$

$$\Delta_{wu} \in \{0, 1\},\ u = 1, 2, 3, \dots, U \tag{30}$$

$$\pi_{wu} \in \{0, 1\},\ u = 1, 2, 3, \dots, U \tag{31}$$

The objective function (1) minimizes the sum of the costs of the three methods of bunkering LNG fuel to a ship. Specifically, the term $\alpha C_T z_T + \alpha C_S z_s + \alpha C_p z_p$ is the per week's fixed cost of the purchased trucks and ships and the port building cost to bunker LNG fuel to ship. The term $\sum_{w \in W}(c_T x_{wT} + c_s x_{ws} + c_P y_{wP})$ is total variable cost of Truck, ship and port to bunker LNG fuel to ships. The term $\sum_{w \in W} p_w \max(0, \tau_{w2} - U_{w2})$ is the extra cost that ship's actual departure time extends the planning departure time. Constraints (2) ensure that exactly one bunkering method should be used to bunker ship w. Constraints (3) and (4) mean that the quantity of ship/truck for bunkering LNG fuel to a ship is less than M and that the number of trucks/ships used to bunker the ship is less than the maximum number of trucks/ships. Constrains (7), (8) and (9) define that the total quantity of bunkering LNG fuel to ship w is equal to/more than the demand quantity of LNG fuel by trucks/ships/the port. In constrains (7), (8) and (9), M is used to ensure the LNG fuel possessed by trucks/ships/the port is more than the demanded quantity. Constrains (7), (8) and (9) always holds because the largest value of y_{wT}, y_{wS} and y_{wP} is equal to 1. Constraint (10) states that ship w can bunker LNG fuel after its arrival. Constraints (11) and (12) state that the beginning time of bunkering LNG fuel to ship w is u. Constraints (13) and (14) ensures that the end time of bunkering ship w is u. Constraints (15) and (16) states that the bunkering time is later than the start time/end time of bunkering LNG fuel to ship w. Constraint (17) defines that the ship is bunkering during the period between the start time to the end time. Constraints (18) and (19) define that the number of trucks/ships used to refuel ship w is equal to the number of trucks/ships bunker ship w in u_{th} if ship w begins bunker in u. Constraint (20) ensures that the ship is bunkered LNG fuel by the port. Constraints (21) and (22) state that the number of the used bunkering trucks/ships in u_{th} hour should not exceed the purchased number of trucks/ships. Constraint (23) states that PTS is bunkering LNG fuel to ship w in u_{th} hours. Constraints (24)-(31) ensure that the domain of the decision variable.

The big-M in Eq. (3) can be set to N_T, because at most N_T trucks can be used to bunker a ship at the same time. Similarly, the big-M in Eq. (4) can be set to N_S. The big-M in Eqs. (7)–(9) can be set to G_w, because, for example, in Eq. (7), if $M = G_w$, then when $y_{wT} = 0$, the inequality always holds as long as $\gamma_{wuT} \geq 0$. The big-M in Eq. (18) and (19) can be set to N_T and N_S, respectively, and the big-M in Eq. (20) can be set to 1.

4.4 NUMERICAL EXPERIMENTS

To evaluate the proposed model, we conduct several computational experiments on a PC (Intel Core i7; Memory, 16 GB, Mountain View, CA, USA). The mathematical model proposed in this study is coded in $C^{\#}$ and implemented in CPLEX 12.6.2.

4.4.1 Performance of the model

We first summarize our parameter setting. We set the planning horizon to 24 hours. The cost of purchasing a truck, purchasing a ship, and building a port to bunker ships is 204 thousand USD, 50 million USD, 11.7 million USD, respectively (Argonne, 2013; Marine & offshore, 2020; Ship and bunker, 2021). The conversion factor is calculated by the purchasing cost divided the 365 days and 24 hours. We assume that the variable cost for a truck, a ship, and a port to bunker a ship is 50 USD/hour, 100 USD/hour, 150 USD/hour, respectively. From World port sustainability program (2020), we obtain that the hourly volume of bunkering a ship by a truck is $60m^3$, the hourly volume of bunkering a ship by another ship is $100m^3$, and the hourly volume of bunkering a ship by a port is $180m^3$. The arrival time and departure time of the ships are randomly generated from 0h to 24h within a planning horizon. The volume of LNG bunkering for the ship is randomly generated from $1000m^3$ to $5000m^3$. For the extra cost if the actual departure time extends the planning time, we set it to 200 USD/h.

Several numerical experiments with different number of ships were carried out to validate the proposed model. Table 4-1 lists the results provided by CPLEX directly. In Table 1, number of ships represent that the total quantity of ships docks at the port to bunker in a week. From Table2, we obtain that the optimal bunkering method is STS compared TTS and PTS. Furthermore, we find that the CPU running time increases in different cases. This means that the total bunkering time for ships is increase by the ships.

Table 3-2: Results provided by CPLEX

Case ID	Number of Ships	The method of bunkering ships	CPU Time(s)
1	10	STS	17
2	15	STS	21
3	20	STS	27
4	25	STS	34
5	30	STS	40

4.5 SENSITIVE ANALYSIS

Some parameters that we set in the ILP model is fluctuated, such as the bunker rate of ships, the purchased cost of ships and variable cost. Hence, we conduct the sensitive analysis by increasing the bunker rate of ships in this section. We choose the first case of Table 2 to do sensitive analysis.

First, we discuss the impact on the optimal number of purchased ships to bunker LNG fuel to ships by increasing the bunker rate. The results as the Table 4-2 indicates that the optimal number of purchased ships decrease from 4 to 3 when bunker rate increases from $750m^3/h$ to 800 m^3/h, which means that $750m^3/h$ is a threshold point. The optimal number of purchased ships is still 3 with the bunker rate increasing from 800 m^3/h to 950 m^3/h , which indicate that the least purchased ships of bunkering LNG to ships is 3.

Table 4-3: The number of purchased ships as bunker rate increase

Case ID	Bunker Rate (m^3/h)	Optimal number of purchased ships
1	750	4
2	800	3
3	850	3
4	900	3
5	950	3

Next, we discuss the impact on the total cost by increasing the bunker rate of ships. From the Table 4-3, two main points can be concluded form the results. First, the total cost is decrease with bunker rate increases because the time of bunkering LNG fuel to ships is decrease. Second, the total cost decrease largely with the bunker rate increase from $750m^3/h$ to $800\ m^3/h$ because the number of purchased decrease, leading the total cost decreasing form 6880 USD to 6010 USD.

Table 4-4: The total cost as the bunker rate increase

Case ID	Bunker Rate (m^3)	Total Cost (USD)
1	750	6880
2	800	6010
3	850	5810
4	900	5610
5	950	5510

4.6 CONCLUSION

LNG, a kind of natural gas, is a promising fuel to replace the traditional fossil fuel in maritime transportation industry as it can reduce the emission and assist in addressing the environmental problems. LNG bunkering is a necessary step to use LNG. There are three common bunkering methods: STS, TTS, and PTS. All methods have its own advantages and limitations. To find the most suitable method of bunkering ships, we develop an ILP model to decide which method is the optimal method to bunker ships. The results obtained in this study show that STS is the optimal method. The results together with the insights obtained can be helpful for the government to build the LNG bunkering station to bunker the ships by STS.

Then, we conduct the sensitive analysis on the bunker rate as it is influenced by the size of the fuel tanks and the demand of LNG fuel of ships. The results of sensitive analysis indicate that the purchased number of bunker LNG fuel ships and the total cost decrease as the bunker rate increases.

This paper also has its own shortcomings. First, some data used in the numerical experiments are randomly generated such as ship arrival time and departure time, and the volume of LNG bunkering for the ship. Hence, in future research, real data can be collected so as to derive more practical insights and conclusions. Moreover, in this study we did not consider the case where more than one ship arrivals at the port simultaneously, where some ships need to wait for bunkering. Thus, in future research, we need to consider a more complex situation by adding the ship waiting time to the ILP model. Second, from the port perspective we suppose that one port offers the bunkering service for LNG fueled ships and do not consider the port competition for bunkering ships. Hence, the port competition for bunkering ships should be included in the future research.

Chapter 5. Conclusions

More than 80% by volume of cargo is transported by ships. The demand of shipping transportation is estimated to increase. Due to some problems e.g., the demand uncertainty of transportation, outbreak of COVID-19 and green transportation requirement, the operation of shipping transportation must be optimized. Thus, this thesis integrates three studies, which is mainly about dealing with the maritime operations management problems: maximizing the profit of booking container slots, opening ports optimization for crew change during COVID-19, and the LNG bunkering framework.

We believe that the three studies can deal with the problems of shipping transportation to some extent and provide the suggestion to government and the industry. But the three studies have shortcomings, which can be improved in the future research. First, at the port level the studies consider simple settings with one port, which is not enough to solve the problem of maritime operation. Therefore, more complex setting with two or more ports should be considered in the future research. Second, the model of each study is not validated due to lack the real data. Thus, in future research, we should collect the history data of related parameters to obtain more accurate results.

Bibliography

Arnet, N. M. L. (2014). *LNG Bunkering Operations: Establish probabilistic safety distances for LNG bunkering operations* (Master's thesis, Institutt for energi-og prosessteknikk).

Argonne Aug. 2013 Accessed on 23 February 2022. https://afdc.energy.gov/files/u/publication/lng_case_study_8_2013.pdf

Alphaliner TOP 100/12 Aug 2021. Accessed 23 Mar. 2022. Available at https://alphaliner.axsmarine.com /PublicTop100/.

BIMCO 21 Apr 2021. Accessed 15 Feb. https://www.bimco.org/news-and-trends/market-analysis

Calderón, M., Illing, D., Veiga, J. (2016). Facilities for bunkering of liquefied natural gas in ports. *Transportation research procedia*, *14*, 2431−2440.

Carotenuto, A., Molino, I., Fasanaro, A. (2012) Psychological stress in seafarers: a review. *International Maritime Health*, 63(4), 188−194.

Chung, Y., Lee, P., Lee, J. (2017) Burnout in seafarers: its antecedents and effects on incidents at sea. *Maritime Policy and Management*, 44(7), 916−931.

Crowl, D. A., Louvar, J. F. (2001). *Chemical Process Safety: Fundamentals with Applications*. Pearson Education.

Davies, P. A., Fort, E. (2013). LNG as a marine fuel: Likelihood of LNG releases. *Journal of marine engineering & technology*, *12*(3), 3−10.

De Beukelaer, C. (2021). COVID-19 border closures cause humanitarian crew change crisis at sea. *Marine Policy*, 104661-104665.

Doumbia-Henry, C. (2020). Shipping and COVID-19: protecting seafarers as frontline workers. *WMU Journal of Maritime Affairs*, 19(3), 279-293.

EIA Dec. 2021. Accessed on 15 April 2022. https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the environment.php

Elsayed, T., Leheta, H., & Shehadeh, M. (2009). Multi-attribute risk assessment of LNG carriers during loading/offloading at terminals. *Ships and Offshore Structures*, *4*(2), 127−131.

Fan, H., Enshaei, H., Jayasinghe, S. G. (2022). Dynamic quantitative risk assessment of LNG bunkering SIMOPs based on Bayesian network. *Journal of Ocean Engineering and Science*.

Feng, C. M., Chang, C. H. (2010). Optimal slot allocation with empty container reposition problem for Asia ocean carriers. *International Journal of Shipping and Transport Logistics*. 2(1), 22−43.

Feng, Y. Y., Xiao, B. C. (2006). Integration of pricing and capacity allocation for perishable products. *European Journal of Operational Research*. 168(1), 17−34.

Forbes 20 June 2020. Accessed on 12 Mar 2022. https://www.forbes.com/sites/rrapier/2020/06/20/bp-review-new-highs-in-global-energy-consumption-and-carbon-emissions-in-2019/?sh=40c80aba66a1

Guo, D., Du, X. J., Wu, G. (2018). Optimization of multi-dimensional container slot allocation based on joint dispatch and mutual renting. In *2018 Chinese Control and Decision Conference,* pp. 6155−6160. Available at https://ieeexplore.ieee.org/abstract/document/8408210.

Hu, J., Huang, Y., Zhao, X. (2019). Research on the slot allocation of container liner under E-commerce environment. *Computers & Industrial Engineering*, 129, 556−562.

Hystad, S., Eid, J. (2016) Sleep and fatigue among seafarers: the role of environmental stressors, duration at sea and psychological capital. *Safety and Health at Work*, 7(4), 363−371.

Iannaccone, T., Jeong, B., Cozzani, V., Zhou, P. (2020). Safety Analysis of Liquefied Natural Gas Bunkering and Simultaneous Port Operations for Passenger Ships. In *International Conference on Offshore Mechanics and Arctic Engineering* (Vol. 84379, p. V06AT06A035). American Society of Mechanical Engineers.

IMO (2020) Circular Letter No. 4204/Add. 14, Coronavirus (COVID-19) – Recommended framework of protocols for ensuring safe ship crew changes and travel during the coronavirus (COVID-19) pandemic.

IMO. 2015. MSC 95/INF.17 information on incidents during bunkering of LNG. London (UK): International Maritime Organization.

INTERNATIONAL LABOUR ORGANIZATION 1 Mar 2019. Accessed 11 Feb 2022 https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/sector/documents/document/wcms_712749.pdf

itfseafarers 12 Sep 2020. Access 19 Jan 2022. https://www.itfseafarers.org/en/news/companies-must-take-crew-change opportunities-uk-and-elsewhere-itf

Iversen, R. (2012). The mental health of seafarers. *International Maritime Health*, 63(2), 78−89.

Jeong, B., Lee, B. S., Zhou, P., Ha, S. M. (2017). Evaluation of safety exclusion zone for LNG bunkering station on LNG-fuelled ships. *Journal of marine engineering & technology*, *16*(3), 121−144.

Jepsen, J., Zhao, Z., Leeuwen, W. (2015) Seafarer fatigue: a review of risk factors, consequences for seafarers' health and safety and options for mitigation. *International Maritime Health*, 66(2), 106−117.

Johnson, T. (2020). Reliability on the spot. Accessed 20 Mar 2022. https:www//.maersk.com/news/articles/2020/02/20/reliability-on-the-spot.

Khouja, M. (1999). The single-period (newsvendor) problem: Literature review and suggestions for future research. *Omega*. 27 (5), 537−553.

Kim, A. R., Kwak, D. W., Seo, Y. J. (2021). Evaluation of liquefied natural gas bunkering port selection. *International Journal of Logistics Research and Applications*, *24*(3), 213−226.

Kim, J., Jang, S. (2016) The relationship between job stress, job satisfaction, and the symptom checklist-90-revision (SCL-90-R) in marine officers on board. *Journal of Preventive Medicine and Public Health*, 49(6), 376−385.

Lam, J. S. L., Zhang, X. N. (2019). Innovative solutions for enhancing customer value in liner shipping. *Transport Policy*. 82, 88−95.

Lee, L. H., Chew, E. P., Sim, M. S. (2007). A heuristic to solve a sea cargo revenue management problem. *OR Spectrum*. 29(1), 123−136.

Lee, Y. G., Kim, J. K., Lee, C. H. (2021). Analytic hierarchy process analysis for industrial application of LNG bunkering: A comparison of Japan and South Korea. *Energies*, *14*(10), 2965.

Lefkowitz, R. Y., Slade, M. D. (2019). Accessed 1 July 2021.Seafarer Mental Health Study.https://www.seafarerstrust.org/wpcontent/uploads/2019/11/ST_MentalHealthReport_Final_Digital-1.pdf.

Lloyd's List 24 Jan. 2022 Accessed on 1 April 2022. https://lloydslist.maritimeintelligence.informa.com/LL1139627/Shipping-emissions-rise-49-in-2021

Mao, Y. W., Shen, L. F. (2016) p-persistent scheme for slot allocation in vehicular networks. In 2*016 83rd IEEE Vehicular Technology Conference*, pp. 1−5. Available at https://ieeexplore.ieee.org/abstract/document/7504429

Maritime, 12 Nov 2020 (2020). Accessed 1 Dec 2021. https://www.maritime-executive.com/article/cost-of-crew-change-skyrockets-due-to-pandemic.

Marine & offshore Oct. 22, 2020. Accessed on 26 February 2022. Available at https://marine-offshore.bureauveritas.com/magazine/client-corner-what-does-it-take-build-lng-bunkering-ship

McLinton, S. S., Dollard, M. F. (2010) Work stress and driving anger in Japan. *Accident Analysis and Prevention*, 42(1), 174−181.

Oldenburg, M., Baur, X., Schlaich, C. (2010) Occupational risks and challenges of seafaring. *Journal of Occupational Health*, 1007160136−1007160136.

Oldenburg, M., Hogan, B., Jensen, H. J. (2013) Systematic review of maritime field studies about stress and strain in seafaring. *International Archives of Occupational and Environmental Health*, 86(1), 1-15.

Oldenburg, M., Jensen, H. J. (2012) Merchant seafaring: a changing and hazardous occupation. *Occupational and Environmental Medicine*, 69(9), 685−688.

Park, S., Jeong, B., Yoon, J. Y., Paik, J. K. (2018). A study on factors affecting the safety zone in ship-to-ship LNG bunkering. *Ships and Offshore Structures*, *13*(sup1), 312−321.

Park, S. I., Paik, J. K. (2022). A hybrid method for the safety zone design in truck-to-ship LNG bunkering. *Ocean Engineering*, *243*, 110200.

Panova, Y. L., Tan, A., Hilmola, O. P., Puvindran, M. H., Xu, H. S., Li, W. D. (2019). Evaluation of e-commerce location and entry to China–implications on shipping and trade. *Journal of Shipping and Trade*. 4(1), 1-25.

Pei, S., Fu, M., Lu, J., Sun, J. (2007) A study on container allocation on shipping routes for liner companies. In *2007 International Conference on Service Systems and Service Management,* pp. 1−6. Available at https://ieeexplore.ieee.org/abstract/document/4280241.

Peng, J. L., Li, X., Liang, Y. N., Zhang, Y. (2017). Research and analysis of slot allocation strategy for hybrid resource scheduling in wireless multi-hop cooperative networks. In *2017 2nd IEEE Advanced Information Technology, Electronic and Automation Control Conference,* pp. 1709−1713. Available at https://ieeexplore.ieee.org/abstract/document/8054305.

Qin, Y., Wang, R. X., Vakharia, A. J., Chen, Y. W., Seref, M. (2011). The newsvendor problem: Review and directions for future research. *European Journal of Operational Research*. 213 (2), 361−374.

Sofreight (2020). Accessed 20 July 2021. https://www.sofreight.com/news_49604.html

Seaman 27 Jul 2020 (2020). Accessed 27 July 2021. https://54seaman.com/news/detail_136550.html.

Seatrade 25 May 2020. Accessed 15 Feb 2022. https://www.seatrade-maritime.com/regulation/singapore-allow-crew-changes-where-seafarer-contracts-have-expired.

Ship and bunker Sep. 21, 2021. Accessed on 25 February 2022. Available at https://shipandbunker.com/news/emea/492479-building-of-bilbao-lng-bunker-terminal-begins

Skramstad, E. (2013). International guidelines for Bunkering LNG as a Marine fuel.

In *17th International conference and exhibition on liquefied natural gas (LNG 17), Houston, 17th April 2013*.

Smith, A.P., Allen, P.H., Wadsworth, E.J.K. (2006). Accessed 2 July 2021. Seafarer fatigue.https://www.seafarerstrust.org/wpcontent/uploads/2019/11/ST_MentalHealthReport_Final_Digital-1.pdf.

Sohu 1 Jan 2021. Accessed 22 July 2021. https://www.sohu.com/a/446396202_683946.

The conversation. 4 May 2020. Accessed 11 Jan 2022. https://theconversation.com/thousands-of-seafarers-are-stranded-aboard-ships-with-no-end-to-their-shift-in-sight-137324

The Maritime Executive 7 Aug 2020. Accessed 19 Jan 2022. https://maritimejamaica.com/News-Events/jamaica-opens-for-crew-changes-and-repatriations

UK Research and Innovation 10 Aug. 2021. Accessed on 20 Mar. 2022. Available at https://www.ukri.org/news/shipping-industry-reduces-carbon-emissions-with-space-technology/

United Nations Conference on Trade and Development (UNCTD). 11 Jun. 2021. Accessed on 18 Mar. 2022. Available at https://hbs.unctad.org/world-seaborne-trade/

United Nations Conference on Trade and Development (UNCTD) 11 Jun 2021. Accessed 15 Feb 2022. https://hbs.unctad.org/world-seaborne-trade/

Ursavas, E., Zhu, S. X., Savelsbergh, M. (2020). LNG bunkering network design in inland waterways. *Transportation Research Part C: Emerging Technologies*, *120*, 102779.

Wang, Y. D., Meng, Q. (2019). Integrated method for forecasting container slot booking in intercontinental liner shipping service. *Flexible Services and Manufacturing Journal*. 31(3), 653–674.

Wang, X., Zhang, R., Yin, M. (2007). An application of slots overbooking in enlarging of container ships. *Journal Shanghai Jiaotong University*. 41(2), 289–292.

Wang, T., Meng, Q., Wang, S., Qu, X. (2021). A two-stage stochastic nonlinear integer-programming model for slot allocation of a liner container shipping service. *Transportation Research Part B: Methodological*, 150, 143−160.

Wagner, S. (2019). Maersk introduces Maersk Spot, a new fully online product that simplifies the buying process for customers. Accessed on 20 Mar. 2022. https://www.maersk.com/news/articles/2019/06/25/maersk-introduces-maersk-spot.

Wang, L. (2014). Research on the Development Forecast of Chongqing Marine LNG Bunkering Terminal Layout Planning. *China Water Transportation*, *14*, 279−280.

World port sustainability program Apr. 25, 2020. Accessed on 24 February 2022. Available at https://sustainableworldports.org/clean-marine-fuels/lng-bunkering/ports/lng-bunker -infrastructure/

Xie, C., Huang, L., Wang, R., Deng, J., Shu, Y., Jiang, D. (2022). Research on quantitative risk assessment of fuel leak of LNG-fuelled ship during lock transition process. *Reliability Engineering & System Safety*, *221*, 108368.

Xuan, S., Hu, S., Li, Z., Li, W., Li, B. (2019). Dynamics simulation for process risk evolution on the bunker operation of an LNG-fueled vessel with catastrophe mathematical models. *Journal of marine science and engineering*, *7*(9), 299.

Yu, Y. U., Ahn, Y. J., Kim, J. K. (2021). Determination of the LNG Bunkering Optimization Method for Ports Based on Geometric Aggregation Score Calculation. *Journal of Marine Science and Engineering*, *9*(10), 1116.

Zhao, X., Ding, W., Su, M., Peng, Y., Song, X. (2022). Comprehensive evaluation method for site selection of LNG bunkering stations in Bohai Rim ports. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1011, No. 1, p. 012048). IOP Publishing.

Zhao, H., Meng, Q., Wang, Y. D. (2019). Exploratory data analysis for the cancellation of slot booking in intercontinental container liner shipping: A case study of Asia to US West Coast Service. *Transportation Research Part C: Emerging Technologies.* 106, 243−263.

Zhao, H., Meng, Q., Wang, Y. D. (2020). Probability estimation model for the cancellation of container slot booking in long-haul transports of intercontinental liner hipping services. *Transportation Research Part C: Emerging Technologies*. 119, 968–987.