OPTIMIZATION MODEL FOR CHEMICAL TANK CONTAINER MANAGEMENT

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering in Engineering Management
(CU-Warwick)
FACULTY OF ENGINEERING
Chulalongkorn University
Academic Year 2020

แบบจำลองเพื่อการหาทางเลือกที่ดีที่สุดสำหรับการบริหารจัดการแทงค์คอนเทนเนอร์บรรจุเคมีภัณฑ์

นายอติวิชญ์ อนันตกิจธำรง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาการจัดการทางวิศวกรรม ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2563

Thesis Title	OPTIMIZATION MODEL FOR CHEMICAL TANK CONTAINER MANAGEMENT
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Field of Study	Engineering Management
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อติวิชญ์ อนันตกิจธํารง : แบบจําลองเพื่อการหาทางเลือกที่ดีที่สุดสําหรับการบริหารจัดการแทงค์คอนเทนเนอร์บรรจุเคมีภัณฑ์. (OPTIMIZATION MODEL FOR CHEMICAL TANK CONTAINER MANAGEMENT) อ.ที่ปรึกษาหลัก : รศ. ดร.มาโนช โลหเตปานนท์

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาแบบจําลองเพื่อการหาทางเลือกที่ดีที่สุดสําหรับการบริหารจัดการแทงค์คอนเทนเนอร์บรรจุเคมีภัณฑ์โดยใช้ตัวแบบโปรแกรมเชิงเส้น ฟังก์ชันเป้าหมายของแบบจําลองนี้คือการหาค่าสูงสุดของกําไรสุทธิโดยพิจารณาตัวแปรตัดสินใจคือ เส้นการเดินทางของแทงค์คอนเทนเนอร์ การขนย้ายแทงค์คอนเทนเนอร์เปล่า และการเช่าแท้งค์คอนเทนเนอร์แบบทันที สมการข้อจํากัดพื้นฐานที่ใช้ในแบบจําลองนี้เกี่ยวข้องกับความสามารถในการรองรับความต้องการแทงค์คอนเทนเนอร์ และสมการการอนุรักษ์การหมุนเวียนของแทงค์คอนเทนเนอร์ ข้อจํากัดเพิ่มเติมเกี่ยวกับการบังคับการขนย้ายแทงค์คอนเทนเนอร์เปล่า และการจัดสิ่งจูงใจทางการเงินอาจถูกนํามาใช้เพื่อส่งเสริมการขนย้ายแทงค์คอนเทนเนอร์เปล่าเพื่อให้แบบจําลองประพฤติเหมือนการดําเนินงานจริงมากยิ่งขึ้น ผลจากการทดสอบแบบจําลองพบว่าค่าใช้จ่ายในการขนย้ายแทงค์คอนเทนเนอร์เปล่าลดลงจากการป้องกันการขนย้ายแทงค์คอนเนอร์เปล่าโดยไม่จําเป็น มากไปกว่านั้นแบบจําลองยังช่วยกําจัดค่าใช้จ่ายการขนส่งในการรับแทงค์คอนเทนเนอร์จากต่างท่าเรือ การลดค่าใช้จ่ายจากการดําเนินการดังกล่าวข้างต้นทําให้กําไรสุทธิเพิ่มขึ้น กล่าวคือแบบจําลองที่ดีที่สุดให้ผลกําไรสุทธิมากกว่าผลการดําเนินงานจริงร้อยละ 5.76 นอกเหนือจากผลการคํานวณของแบบจําลอง ค่าราคาเงาจากรายงานการวิเคราะห์ความอ่อนไหวของแบบจําลองยังสามารถบอกข้อมูลเพิ่มเติมเกี่ยวกับความสามารถในการทํากําไรของแต่ละเส้นการเดินทางของแทงค์คอนเทนเนอร์ รวมไปถึงบ่งชี้ข้อจํากัดของปริมาณความต้องการแทงค์คอนเทนเนอร์ที่สามารถเพิ่มขึ้นภายใต้ตัวแปรที่เหมาะสมที่สุดที่ได้รับจากแบบจําลอง ผลจากการศึกษาแบบจําลองทั้งหมดดังกล่าวข้างต้นเน้นย้ําถึงข้อดีในการใช้แบบจําลองเพื่อการหาทางเลือกที่ดีที่สุดเพื่อเป็นหลักฐานสนับสนุนการปฏิบัติงานจริงในการบริหารจัดการแทงค์คอนเทนเนอร์บรรจุเคมีภัณฑ์

สาขาวิชา	การจัดการทางวิศวกรรม	ลายมือชื่อนิสิต	
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6171219621 : MAJOR ENGINEERING MANAGEMENT
KEYWORD: Optimization, Empty container repositioning, Linear programming, Sensitivity analysis

Atiwich Anantkijthamrong : OPTIMIZATION MODEL FOR CHEMICAL TANK CONTAINER MANAGEMENT. Advisor: Assoc. Prof. MANOJ LOHATEPANONT, Sc.D.

Owing to lack of appropriate tool for operational decision, this study aims to develop an optimization model for chemical tank container management using linear programming methodology. The objective function is to maximize net profit while taking container routing, empty container repositioning, and container spot leasing into account as decision variables. The basic constraints used in the model are related to spot demand accommodation and conservation of tank container flows. On top of that, additional repositioning constraints and financial incentives may be utilized to promote empty container repositioning, hence, allow the model to behave alike actual operation. The model results show that empty container repositioning cost is reduced by prevention of unnecessary empty container repositioning. Long-distance trucking to pick-up tank containers from other ports may also be eliminated. These ultimately turn into higher profit. That is to say, the model give 5.76% higher profit compared to actual operation. In addition to that, shadow prices obtained from sensitivity report add more insight on identification of each origin-destination route profitability as well as a limitation of potential increased volume of demands under optimal operational decision derived from the model. These highlight the advantages of having the use of optimization model as supportive evidence over the merely use of spreadsheet and individual adjustments for tank container management.

Field of Study:	Engineering Management	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

ACKNOWLEDGEMENTS

With the deepest gratitude, the Author wishes to express his sincere thankfulness to his advisor, Assoc. Prof. Dr. Manoj Lohatepanont, Faculty of Engineering, Chulalongkorn University, for his fruitful guidance and perpetual supervision throughout this research.

The Author also would like to express his gratefulness to Prof. Dr. Parames Chutima, examination chairman and Assoc. Prof. Jeerapat Ngaopresertwong, examination committee, for their useful recommendations and helpful corrections for the final thesis report.

His truthful gratitude additionally goes to Mr. Koo Kim, Managing Director of the company that the Author currently works for. His great assistance in providing company's historical data is the most valuable for the study. His strong support and abundant advices are wholeheartedly appreciated.

Atiwich Anantkijthamrong

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Introduction

1.1 Research background

Due to high downstream industrial consumption, the chemicals industry has grown steadily over the decades, especially in newly emerging markets in Asia. Over the last few years (2016-2019), chemicals market has grown steadily around 3.5-4.5%, as shown in Figure 1. In 2024, chemicals market in the Asia-Pacific region is forecasted to witness an increase of 18% compared to 2019 to reach a value of $3,107.4 billion (MarketLine, 2020). These developments provide a broader choice of both prices and grades of many chemical commodities for consumers and underscore the importance of the logistics and transportation services needed to accommodate transport demands of chemical cargoes.

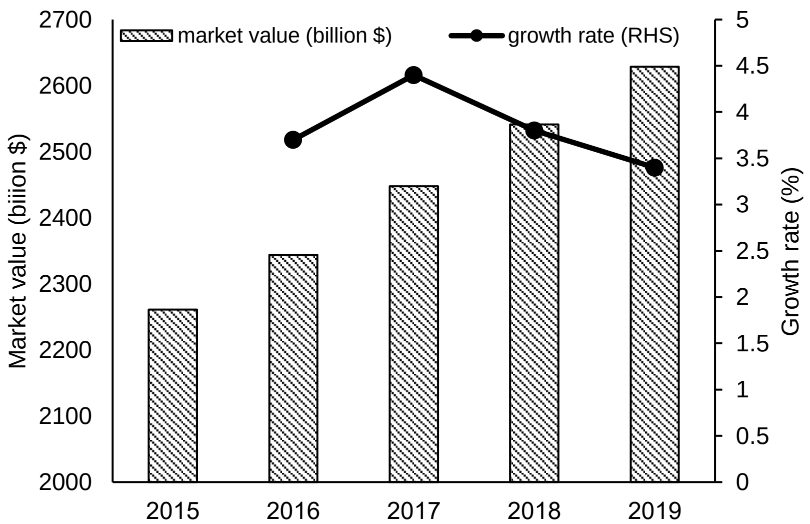

Figure 1 Asia-Pacific chemical market value and growth rate between 2015 - 2019

There are several modes available to transport chemical products from an origin to a destination, namely, parcel tankers, road tankers, tank containers, containerized Intermodal Bulk Containers (IBC) and drums. Among these, tank container plays the most important role in today's chemical logistics. It is stated that tank container has a very great contribution in transportation choice which has been accounted for more than 90% of non-bulk cargo movements (International Tank Container Organization, 2011). Using tank container offers various advantages over others option of chemical transportation. It is a statement from (Xing et al., 2019) said that using tank container is safer and less likely to cause product leakage during transportation and loading/unloading processes. It provides better space utilization which also means better efficiency. Specifically, it offers 43% more payload volume compared to packed drums in typical dry containers. Moreover, tank container does not require special port infrastructure to handle. According to the International Tank Container Organization (2020), the global tank container fleet, as of January 2020, stands at 652,350 units. This figure represents a growth of 7.9% compared to last year. In fact, as shown in Figure 2, tank container fleet has been growing gradually over the decade. This scenario reflects the potential development of tank container industry along with the growth of chemical industry.

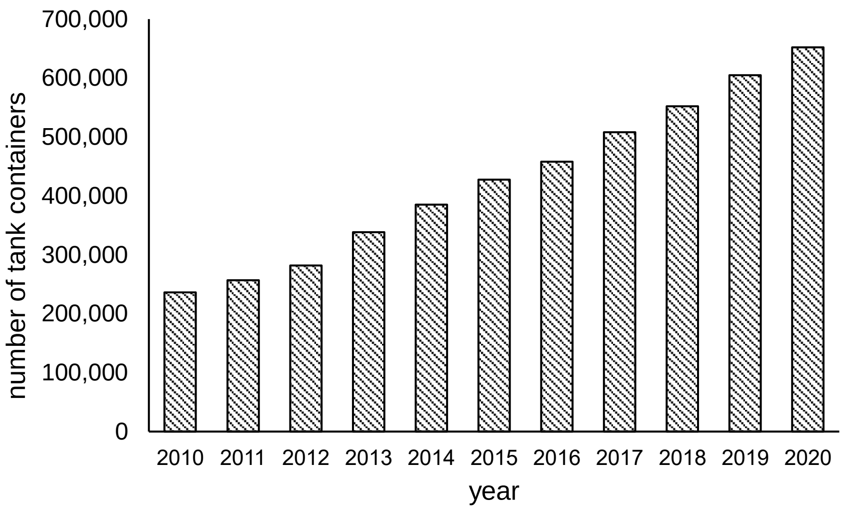

Figure 2 Global tank container fleet size since 2010 to 2020

Similar to general container business, tank container company is facing many operational challenges from the imbalance of trade flows across different countries. It cannot be denied that, in Asia region, there is a remarkable difference of advancement in both upstream and downstream petrochemical industries among countries. Some of them, such as China, South Korea, and Japan, are presently considered as the world leading in petrochemical industry with the export capability. Whereas others like Indonesia and Vietnam are at some distances behind and need to import chemical products to use in manufacturing activities. Thus, there are major flows of loaded tank containers from those of the export-dominant to the import-dominant countries. Petrochemical-related industry is also, in addition, subjected to the uncertainty of supply and demand from the chemicals markets. For instance, once one chemical plant is on emergency shutdown or even temporarily turnaround period, none of the product is produced. This causes a sharp fall in shipments at its port of origin. The demand at other ports which have the plant producing the same chemical products increase vice versa. From these reasons, empty tank container repositioning becomes necessary to satisfy the imbalanced import and export flow volume as well as the supply uncertainty and the volatility of demands in chemical markets.

Two types of company exist in regional tank container operation, namely, chemical company and logistics intermediary. The chemical company requires tank container for its logistics needs and typically purchase or lease tank container for long-term use and manage them independently to supply the company's value chain. This type of operation is not exposed to external uncertainties and challenges as described in above mentioned because it only manages logistics activity for its own supply chain, which could be accurately forecasted and planned.

Meanwhile, the logistics intermediary, often-referred to as third-party logistics or even forth-party logistics company, manages their tank containers and provides transportation services for multiple and different customers. These companies typically call themselves *tank container operator (TCO)*. Unlike the chemical company, TCO encounters the imbalance of trade flows as well as supply and demand uncertainties in chemicals logistics market. It regularly serves hundreds of customers in various terms and requirements in different supply chains.

Company A is a TCO established in 2003. The company is headquartered in South Korea with 5 regional subsidiaries: Thailand, China, Indonesia, Malaysia, and Singapore. They collaboratively organize chemical transportation through tank containers with a strong focus on Intra-Asia network countries, e.g., Taiwan, Thailand, Japan, China, South Korea, Vietnam, Indonesia, and Malaysia. The company's serves more than 100 chemical users as well as manufacturers with more than 20,000 TEUs of import and export shipments. The company's services cover 12 countries, more than 30 port calls, and approximately 200 origin-destination routes. Throughout its network, the company inevitably confronts with the imbalance of chemical trade flows in reginal markets. For example, Figure 3 illustrates the magnitude of the imbalance between import and export container flows in South Korea between 2012-2019. It shows that, the numbers of export shipments were considerably higher than import shipments every year. Meanwhile, as shown in figure 4, Vietnam experienced great amount of import containers but had only few exports. This is an evidence of the needs of empty container repositioning from import-dominant countries to support shipments at export-dominant countries.

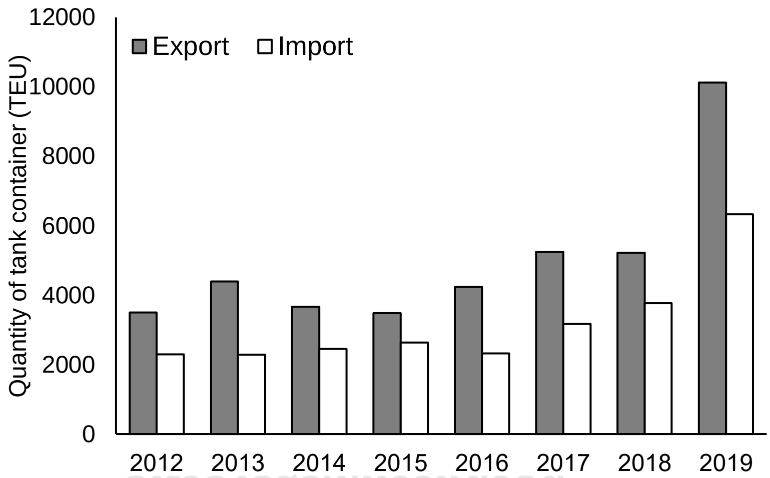

Figure 3 Export and Import tank container at South Korea between 2012 and 2019

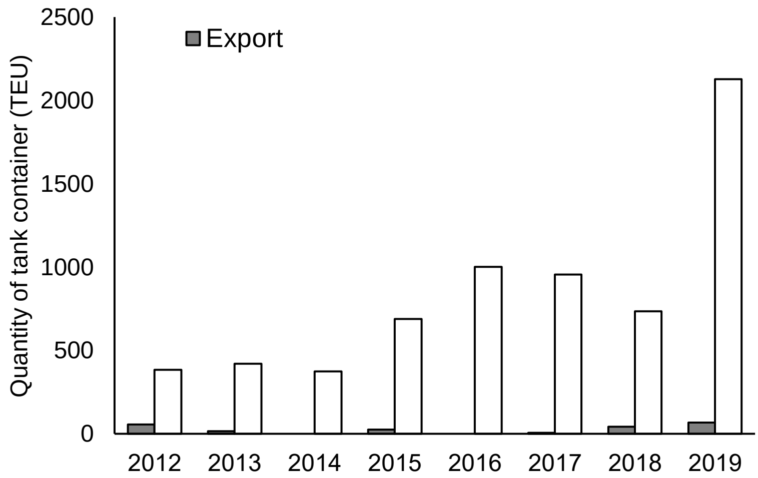

Figure 4 Export and Import tank container at Vietnam between 2012 and 2019

Having said that, empty container repositioning scheme is dynamic and much more complex than those from import-dominant to export-dominant countries. As seen from figure 5, between 2012 – 2016, the historical volumes of export shipments from Indonesia were higher than import shipments. Whereas, in recent years between 2017 – 2019, the export volumes were lower. Noticeably, the exports volume in 2019 experienced a sharp increase compared to 2018, which might exceed the import volumes in the next year. This indicates both inbound and outbound demand uncertainties of chemical shipments of Company A's customer, which have a strong effect on tank container flow and network. From this evidence, Company A requires an effective tool to carefully manage tank containers.

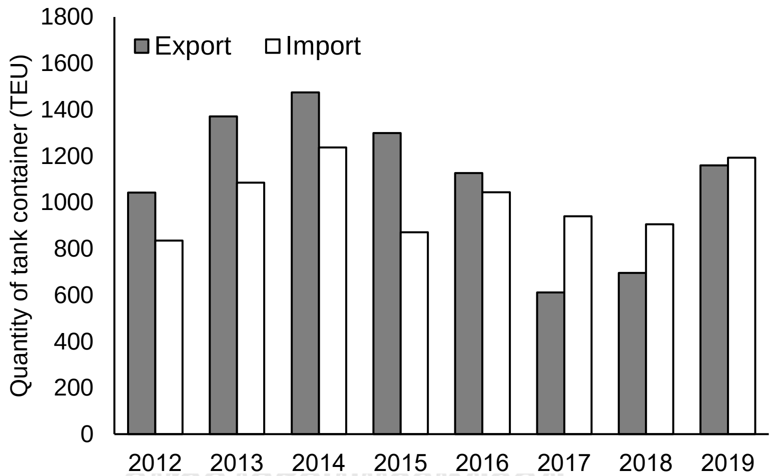

Figure 5 Export and Import tank container at Indonesia between 2012 and 2019

Tank container management is a critical task for any TCO including company A. That is because the company must have sufficient tank containers available to support customer demands. Shortage in tank containers may result in poor customer satisfaction which may adversely impact future bookings. On the other hand, tank container surplus incurs additional and unnecessary cost at terminals and depots, for example, detention and over-free time storage charges.

In general, there are two different types of customers, namely, contract customers and spot customers. Contract customers is the customers that company joins their tenders. Once bidding process completed, the contract is awarded by indicating fixed selling rates, forecasted tank container demand volume, and specific trade lanes to the company who won the bidding. The demand received from contract customer is referred to as *contract demand*. Spot customer is the customer who request the quotation from the company at any time before sending the booking. The selling rates are quoted and send back. The demand received from spot customer is referred to as *spot demand*. Due to the niche market of tank container operation, Xing et al. (2019) stated that TCO may reject some customer demands without losing future businesses. Thus, while a TCO must accommodate all *contract demand*, it may selectively choose to accommodate *spot demand* depending on profitability, available tank containers, and origin-destination routing.

To manage tank container, there are two areas to be considered, namely, *container routing* and *empty container repositioning*. *Container routing* involves deciding how the containers flow from a port of origin to another port of destination. The origin-destination pair is regularly indicated by customers in quotation-booking process.

As for *empty container repositioning*, it should be arranged from import-dominant to export-dominant ports in the most the most time- and cost-efficient manners. In addition to empty container repositioning, *spot leasing* is possible in case of any unplanned shortage to prevent loss of sales due to container unavailability. Ultimately, it cannot be denied that all of these operational activities in tank container management thoroughly contribute to company profitability.

Container routing, *empty container repositioning*, and *spot leasing* decisions in container management are intertwined. In other words, they are complex and highly related to each other. Thus, TCO needs an appropriate tool to rationally analyze and effectively determine operational plans. Company A, however, lacks necessary decision support tool for realistic operation. The company presently relies on excel spreadsheet and basic judgement from individuals, which could possibly lead to errors and suboptimal decisions. For instance, the company may make a decision to accept container requests even though it may not have sufficient tank containers on execution date. Or the company may unknowingly accept early but low profit margin booking instead of late-arriving but high profit margin on a later period. These circumstances may result in lower operational as well as financial performances.

In recent literatures, the established models focus on general container management in shipping line and intermodal operations. The studies in the context of tank container for chemical logistics from Erera et al. (2005), Karimi (2009), Xing et al. (2019) are not applicable to adopt in Company A operations. So that, in this work, the author would like to develop an optimization model for tank container management with the objective to maximize the profit by simultaneously taking *container routing*, *empty container repositioning*, and *spot leasing* into account.

1.2 Objective

This study is aimed to develop an optimization model for tank container management to maximize the profit by considering *cargo routing*, *empty container repositioning*, and *spot container leasing*.

1.3 Scope of the Study

In this work, the author studies tank container operation in 10 countries, namely, China, Japan, Indonesia, South Korea, Malaysia, Thailand, Taiwan, Vietnam, Hongkong, and Singapore. The container flows across these countries are simplified as shown in Figure 4. Total of 34 ports that have significant amounts of flow were selected. Port names and their abbreviations are shown in Table 1. There are 135 origin-destination demand routes and 35 origin-destination empty repositioning routes.

Figure 6 Example of tank container flow in company A operation among Intra-Asia country

1.4 Expected Benefits

1. To use the developed model for the comparison between computational results and company's historical record.
2. To use the developed model in company operations to anticipate the needs of empty repositioning and container spot leasing.
3. To use the developed model in company operations to simulate company profitability under various circumstances during contract customer bidding process.

Table 1 List of ports, countries, and their abbreviations in scope of the study

Item	Port name	Port name abbreviation	Country	Country abbreviation
1	Bangkok	BKK	Thailand	TH
2	Leam Chabang	LCH	Thailand	TH
3	Keelung	KEL	Taiwan	TW
4	Kaohsiung	KHH	Taiwan	TW
5	Taichung	TXG	Taiwan	TW
6	Belawan	BLW	Indonesia	ID
7	Jakarta	JKT	Indonesia	ID
8	Surabaya	SUB	Indonesia	ID
9	Incheon	INC	South Korea	KR
10	Gwangyang	KWY	South Korea	KR
11	Pusan	PUS	South Korea	KR
12	Ulsan	USN	South Korea	KR
13	Gunsan	KUV	South Korea	KR
14	Shanghai	SHA	China	CN
15	Lianyungang	LYG	China	CN
16	Nanjing	NKG	China	CN
17	Qingdao	QDO	China	CN
18	Zhangjiagang	ZJG	China	CN
19	Nansha	NAN	China	CN
20	Huangpu	HUA	China	CN
21	Pasir Gudang	PGU	Malaysia	MY
22	Port Klang	PKG	Malaysia	MY
23	Ho chi Minh	HCM	Vietnam	VN
24	Hai phong	HPH	Vietnam	VN
25	Moji	MOJ	Japan	JP
26	Nagoya	NGO	Japan	JP
27	Tokyo	TYO	Japan	JP
28	Kobe	UKB	Japan	JP
29	Yokohama	YOK	Japan	JP
30	Iwakuni	IWK	Japan	JP
31	Shimizu	SMZ	Japan	JP
32	Osaka	OSA	Japan	JP
33	Hongkong	HKG	Hongkong	HK
34	Singapore	SIN	Singapore	SG

Chapter 2

Theory and Literature Review

In this chapter, a very brief background of freight transportation is firstly introduced. Tank container and its business operation are then subsequently described. After that, Challenges in tank container business operation are added up including fleet sizing, container leasing decision, empty container repositioning, and revenue management. Some relevant literatures related to empty tank container repositioning (ECR) planning model were accordingly reviewed.

2.1 Freight Transportation

2.1.1 Unimodal freight transportation

As implies by its nomenclature, unimodal freight transportation is the mean of transportation of goods by using only single mode of transport. It is majorly a road haulage used for door-to-door shipment from origin to destination that connected by land. Even though it was claimed that unimodal freight transportation is the most flexibility and cheapest, it highly causes carbon footprint per unit of transport which consider as a major drawback.

2.1.2 Multimodal freight transportation

Multimodal freight transportation is defined as the transportation of goods by at least two different modes of transport from one country of origin to the desired destination in a different country (United Nations, 1980). The loading unit on multimodal transportation can be box, drum, container, road vehicle, and sea vessels.

2.1.3 Intermodal freight transportation

Intermodal freight transportation is, in fact, particularly considered as a type of multimodal freight transportation. Macharis and Bontekoning (2004) defined intermodal transportation as the transportation from an origin to the destination by the combination of at least two modes of transport in a single transport chain without any changes of container unit. The main characteristic of intermodal transportation is also highlighted by Crainic et al. (2018) that it is a movement of goods without any physical handling of products inside the transported containers. By this, this type of freight transportation is mostly suitable for chemical transportation and logistics. Reason being, it prevents direct handling of chemical products which some of them are categorized as dangerous (DG) cargo.

2.2 Tank Container

Tank container, also known as portable tank or ISO tank, is a cylindrical pressure vessel set inside of an International Standard Organization (ISO) frame (as depicted in Figure 7). The dimension of tank container is identical to dry box container which generally equal to 6.05 meters long, 2.40 meters wide and 2.40 meters high (20-feet equivalent unit, TEU). It also uses the same type of corner casting technique as those of dry box containers. This allows tank containers to be lifted and stacked on the top of each other or even regular containers using the same equipment and port infrastructure. Tank container is desired and manufactured in different capacity. A standard tank container generally has a capacity of 25,000 liters and gross weight of 60 metric tons. Due to its containerized characteristic, tank container is considered as one of intermodal transportation mode.

Figure 7 Tank containers for chemical transportation

2.3 Tank Container Business Operation

Tank container business operates in the container transport chain, as depicted in Figure 6. The Consignor (or shipper) is the customer who require empty tank container to transport their chemical cargoes. Shipping company, or a tank container operator in this case, is responsible for preparing and providing empty tank containers as request by customers. Typically, the container is stored at inland depots and transport to the customer door for loading. After the cargo are completely loaded, the containers are relocated to the terminals or ports waiting for the planned vessels to depart as booked schedule. These laden tank containers may involve numbers of shipping service in transshipment ports until their reach the destination. Once arrived, the laden tank containers would be trucked to the consignee who is the users of transported cargo for unloading. After that, the empty containers should be moved to designated depot to do cleaning, maintenance, and preparation for the next allocation in the future if there are any customer demands. Interestingly, it can be seen that tank container transport chain does not only consist of forward laden container, but also involve backward flow of empty container due to trade imbalance. One important difference between laden container flows and empty container flows is that the former is driven externally by the customer demands whereas the latter is driven by the laden container flows and determined internally by the shipping companies or service providers themselves. Managing empty container flow is a big challenge in tank container operation.

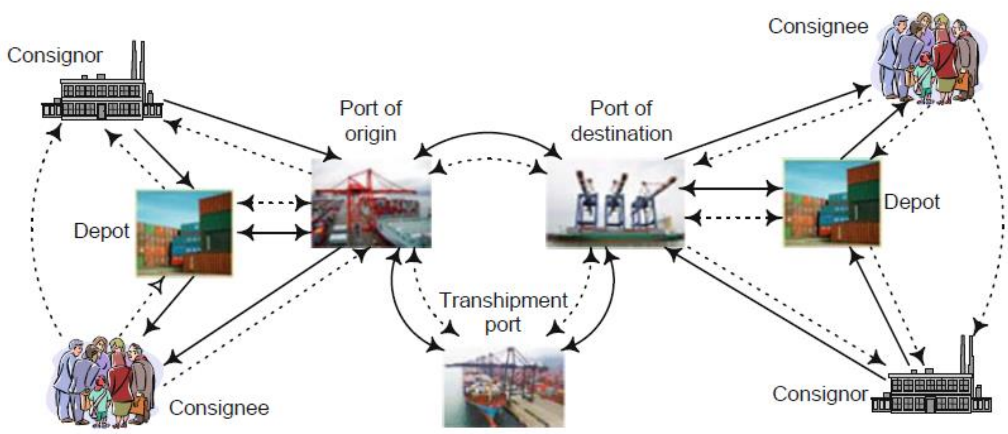

Figure 8 Tank container transport chain (Song and Dong, 2012)

2.4 Challenges in Tank Container Operation

2.4.1 Fleet sizing

Fleet sizing aims to determine the quantity of container needed to be purchased and kept in the company fleet. It is quite a long-term decision because tank container typically has a long lift time which is almost 15 years. Size of container fleet is considered as one of the most significant factors in tank container management. On one hand, small container fleet size requires less capital investment and has lower handling as well as maintenance costs. It is, however, at risk of losing customer orders due to container unavailability (Dong and Song, 2009). On the other hand, large container fleet size means that the owner may have more change to fulfill customer demand in a variety of destinations.

2.4.2 Container leasing decision

The container leasing strategy emerged during the substantial growth of containerization to use as an alternative way of container purchasing. It helps the shipping lines to save huge amount of required capital and enables them to run the businesses with both temporal and geographical demand fluctuations (Rodrigue, 2013), by reduce fleet size and specific region leasing, respectively. In general, it is agreed that freight operators construct their fleets by the mixing of owned containers and leased containers. Demand volatility in global container market, however, makes container company face up with difficulties in capacity planning as well as leasing decision. Container leasing enable freight operator to achieve cost effectiveness and efficiency. Leading in spot contract is considered a one promising solution to tackle with container shortage and surplus situation (Wu and Lin, 2015). It is typically used for short-run peak demand, unplanned requirement in specific geographical location, and a trial in new services routes.

2.4.3 Empty container repositioning

Apart from fleet sizing and container leasing, empty container repositioning is also one of the most important concerns in operational decision regarding container management (Dong and Song, 2012). That is, it can reduce container waiting time and increase container utilization. Not only those of economics perspectives, but empty container repositioning also has sustainability and environmental impact on the society.

The fundamental reason for empty container repositioning is the trade imbalance across the region or even the country. According to the published date from United Nations, the container trade volume from Asia to European countries was between twice and three-times of the volume in the opposite direction in the last decade. In other words, at least half of the containers moving westward to Europe were sent back empty. Notably, this empty repositioning is quite necessary for the container company to sustain its operations. However, it sometimes can be noticed as waste. The reason behind this is that empty repositioning always incurs some costs but does not give a value until it has already utilized. Thus, it is a critical task for container operator to manage empty repositioning just-in-time at profitable transportation cost.

2.4.4 Revenue management

Firstly adopted by and successfully applied to the airline company, revenue management, also known as, yield management is defined as the management of product and service which aim to maximize the revenue in stochastic business environment. (Zurheide and Fischer, 2015 and Meng et al., 2019). It is claimed by Hellermann (2006) that revenue management is a very useful tool when applied products or services with limited capacity, low profit margin, and have specific market segment. The basic structure of revenue management is depicted in Figure 9. below. It is classified to two different types of decision making which are resource allocation and product pricing.

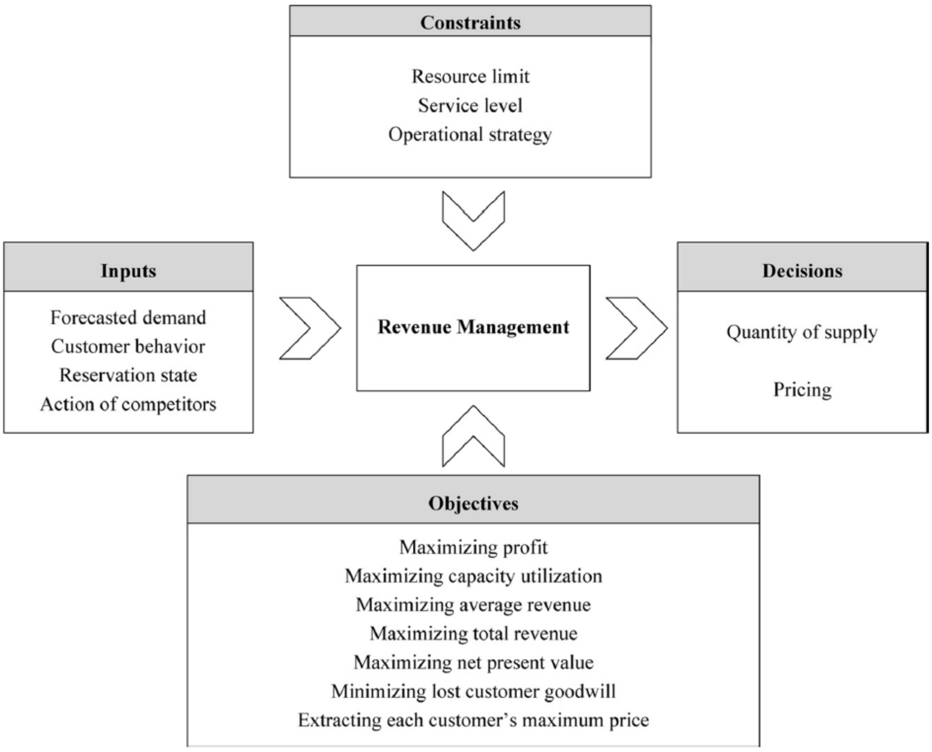

Figure 9 A basic structure of revenue management (Weatherford and Bodily, 1992)

As for logistics industry, especially shipping liners who provide intermodal transportation, the use of revenue management technique is still limited. Incumbents usually manage freight rates and made the quotation prices based on their past experiences and anticipation of future demand in the market. More importantly, the demand fulfillment is generally desired using first-come first-serve practice. The acceptance of orders is, in addition, judge by managerial level with a priority regarding to value or even relationship of customers.

In general, container operator company have two different type of customer which can be categorized as contractual customer and spot customer. The contractual customer signs a long-term contract that stipulate fixed freight rates and certain amounts of required containers in that specific period. This type of customer is, normally, large manufacturers or retailers who have quite big volume and stable demand in particular origin-destination route. They, thus, have more bargaining power over container shipping company. On the other hands, spot customer is the one who intend to use company service only if the expected rated are meet. These two types of customers have a great different contribution to the container demand and revenue. Hence, leveraging both contract and spot demand may increase profitability of tank container company.

2.5 Literature review on empty container repositioning planning model

In this section, the Author would mention to different planning models of which explicitly takes empty container repositioning into account in proposed operational studies. Literally, in addressing the problem of empty container repositioning, there are 3 different of planning levels to be considered, as shown in Figure 10, namely, strategic, tactical, and operational level. The strategic planning is the most long-term planning. It typically includes large capital investment, physical network design, fleet sizing, and service policy arrangement of containers. The tactical planning is a decision making over a moderate time frame which aims to ensure an efficiency of resource management (Crainic and Laporte, 1997). According to Crainic (2000) and Wieberneit (2008), the tactical planning involves numerous critical operational decision such as selection of service routes, origin-destination tragic distribution, and empty container balancing strategy. As for the operational planning, it is a decision making based on highly dynamic environment whether they are supply uncertainty and demand volatility. Thus, resource allocation and short-term leasing contract are considered as operational planning. Optimization of regional empty container repositioning is to satisfy demand of empty container request from customer. Operational planning is divided into 2 separate optimization problems which are container allocation and routing model. Container allocation model focus on the best container distribution of empty container in order to fulfill both known and forecasted demand. The vehicle routing model aims to minimize overall both laden and empty container transportation cost. It provides a lists of tank container quantity as well as origin-destination route that needed to be re-located in the next time-period (Crainic et al., 1993). According to literature review by Braekers et al. (2011), there are many studies in dry container operations that consider empty container repositioning in the proposed models. The relevant literature is classified by Song and Dong (2012) into three groups as follows;

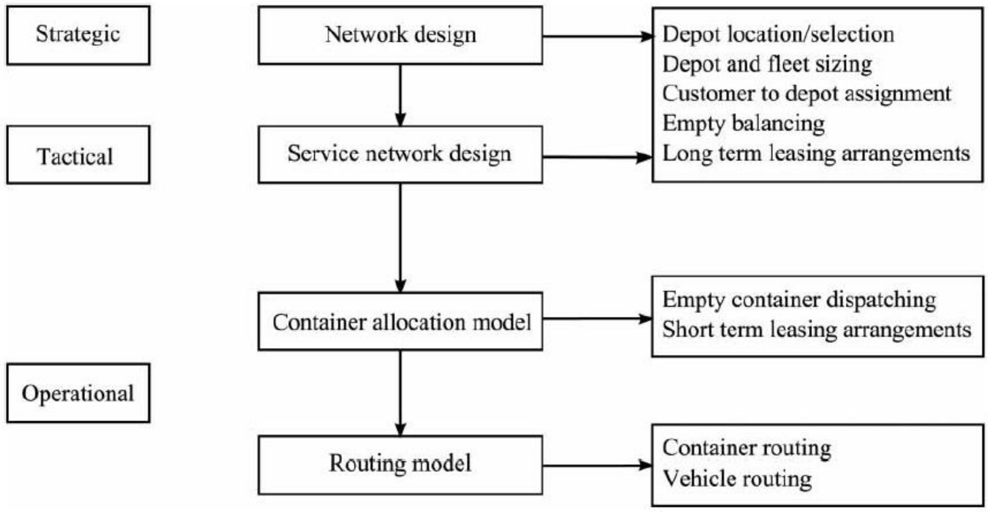

Figure 10 Overview of planning model (Lam et al., 2007)

2.5.1 Empty container repositioning in seaborne shipping network

In this first group, the study merely focuses on empty container repositioning in general port-to-port shipping network. Lai et al. (1995) developed a simulation model for the shipping company operational activities across 11 ports and used heuristic methodology to find cost-effective policy for empty container repositioning. Feng and Chang (2008) proposed a two-stage linear programming model considering safety stock management for Intra-Asia shipping service route. The first stage is to identify container safety stock at each port and the second stage is to solve transportation problem of empty container quantity between ports using linear programming. Song and Dong (2011) introduced repositioning policy in shipping service routes with typical topological structures based on container flow balancing. Two types of flow are considered which are point-to-point balancing and coordinated balancing of the whole service route. A simple heuristic algorithm is presented to solve these balancing problems. The numerical result shown that coordinated balancing outperform point-to-point repositioning strategy in both deterministic and stochastic situations. The advantage of this shipping service modelling for empty container repositioning is that it simplifies the routing decision which allow near-optimal simulation results aiming to minimize total operating cost. Nevertheless, it excludes some important characteristics of containerized business and transport operation.

2.5.2 Empty container repositioning in intermodal transportation network

In this group, instead of port-to-port network in ocean liners operation, intermodal or inland networks are mainly explored. Empty repositioning between importers, exporters, container depots and port terminals are studied. Crainic et al. (1993) proposed the first model which specifically investigate empty container repositioning in inland transportation networks. They presented two dynamic deterministic model to deal with empty container allocation in both single and multicommodity in large container shipping company. In addition, they also developed stochastic model to handle supply and demand uncertainties. Choong et al. (2002) investigated the effect of planning horizon on empty repositioning plan for intermodal transport using container-on-barge operation as example. Integer programming method was used with the objective to minimize overall cost. The study shown that long planning horizon give better choice on choosing cheaper transportation mode.

2.5.3 Empty container repositioning under other decision-making problems

Cranic et al. (1993) firstly explored container fleet size and empty repositioning relation in one model in inland transportation network. Dong and Song (2009) considered container fleet sizing along with empty container repositioning problems in stochastic environment for liners shipping industry. A simulation-based optimization is modeled using Genetic Algorithms to simultaneously determine container fleet size and repositioning policy by minimizing total operating costs. Not only those operational determinations, but the model is also claimed as a useful tool to design safety stocks at each port. Dong and Song (2012) explored the impact of inland transportation lead time on an optimal container fleet size in both deterministic and stochastic environments. Three decisions are incorporated in rule-based policy namely, customer demand fulfillment, laden container allocation and empty container repositioning. They indicated that further study on multiple decision such as leasing deserves future attentions.

As for container leasing problems with empty repositioning, Moon et al. (2010) studied the problem between purchasing and leasing options by looking at empty container repositioning needs. A mixed integer linear programming and two Genetic Algorithms were proposed with an objective to minimize cost while reduce the imbalance of container flow. The model contains number of empty containers required, number of leased and purchased containers, and number of leasing containers return as decision variables. In fact, there are much more literatures which address on container leasing with empty container repositioning. However, most of them implicitly consider spot leasing option in the model (Lai et al., 1995; Cheung and Chen, 1998; Karimi et al, 2005; and Lam et al., 2007). That is, they generally employed an assumption that a container would be leased from spot market when container in company fleet is shortage in meeting demands. The lease-in container then subsequently returned to lease on the next future period.

In regular tank container flow, efficient laden container routing has a strong effect on empty repositioning. Brouer et al. (2011) proposed a mathematical model to solve dynamic cargo routing problems with empty container repositioning in liner shipping company. The objective of study is to maximize profit subject to repositioning cost and container availability. Bell et al. (2011) promoted a promising fleet assignment model for global maritime operation using basic linear programming. They investigated the effect of service frequency, transportation time, and port capacity on both laden and empty flows of container. The objective function is to minimize sailing time and container idling at the port. A set of data in various origin-destination pairs were assigned. Song and Dong (2012) considered joint cargo routing and empty container repositioning problem at under multiple service routes, vessels, and voyages using integer programming. The aim of the study is to minimize total relevant costs, i.e. container lifting cost, backlogs order cost, demurrage cost, and empty container repositioning cost. Erera et al. (2005) integrated tank container routing and empty repositioning in one model using a deterministic multi-commodity flow on a time-expanded network. Three alternative empty positioning strategies were simulated namely, weekly repositioning, bounded daily repositioning, and unbounded daily repositioning. The result indicates that integration of container routing and repositioning decision can reduce container fleet size as well as operating cost.

Table 2 Summary of relevant literatures in empty container repositioning model under other decision-making problems

Authors	Method	Objective function	Addressed problems			
			Fleet sizing	Empty container repositioning	Container leasing	Cargo routing
Erera et al. (2005)	deterministic	Cost minimization		✓		✓
Karimi et al. (2005)	deterministic	Cost minimization		✓	✓	✓
Dong and Song (2009)	simulation-based	Cost minimization	✓	✓		
Moon et al. (2010)	stochastic	Cost minimization		✓	✓	
Brouer et al. (2011)	stochastic	Profit maximization		✓		✓
Xing at al. (2019)	simulation-based	Profit maximization		✓	✓	✓

Table 2 summarizes six relevant literatures related to the work on mathematical model development to address empty container repositioning under other decision-making problems. It can be clearly seen that cost minimization primarily gains attentions from researchers as the model objective, whereas profit maximization dominates this area in the last decade. In addition, it cannot be denied that most of literature focus on general container. As for specialized tank containers for chemical logistics, apart from Erera et al. (2015), there are a few studies that address on this fields. Karimi et al. (2005) developed a novel linear programming for scheduling tank container movements for chemical logistics based on generated event simulation with an aim to minimize total costs. Loaded container, empty container, and leased container were considered as flow variables associated in a model. Furthermore, they proposed the extension of model to present a reality of tank container operation. Many operational factors were included such as alternate shipping routes, container cleaning, multi-substitutable container, non-uniform holding costs, containers for storage, and revenue management. However, they did not take into account cargo routing in their model. Xing et al. (2019) identified key problems in tank container management which are time gap between demand booking and its execution, lack of operational support in decision making, process uncertainties, and surely, empty container repositioning. Thus, they developed a simulation-based two-stage optimization model to deal with those challenges including demand fulfillment and choices of freight forwarder. The first stage is to tactically set inventory levels of tank containers and control policy for empty container repositioning while the second stage is an integration of operational decisions, for example, job acceptance and rejection decision, container operations decisions as well as empty container repositioning. Although this developed model seems rigid in the context of tank container operator operation, it did not consider the handling of different type of demands, namely, contract demand and spot demand, which is considered as important factor in operation plan. It is agreed that uses of advance methodologies like stochastic and simulation-based model allow developed model to tackle with uncertainties of parameters and complexity of scenarios. Stochastic model necessitates some forms of probability distribution which some set of data may not express probabilistic dependence. Simulation-based model requires algorithms which could make the model complex and time-consuming to solve. From those points mentioned before, the author would newly develop optimization model for chemical tank container management using deterministic linear programming methodology by taking three main decision variables which are container routing for both contract and spot demand, empty container repositioning between international ports as well as domestic ports, and container spot leasing into account. Furthermore, the author would also make use of sensitivity report to perform an analysis on possible changes of spot demands parameter to deal with such uncertainties in real operations. This model would provide a simple tool for tank container operator including Company A to effectively manage tank container fleet.

Chapter 3
Research Methodology

This optimization model for chemical tank container management is developed using linear programming method. The model attempted to find the appropriate quantity of both contract and spot demands accommodation, empty container repositioning, and container spot leasing in tank container operation while maximizing the profits. The details of mathematical formulation, computation experiment, and sensitivity analysis are described in these following sections.

3.1 Problem description

Consider tank container movement, as portrayed in Figure 9., loaded tank container departs port of origin and arrive at port of destination in specified quantity as per requested by customers. In general, there are two types of customers in company A business namely contract and spot customer. Contract customer is the one who signs long-term agreement in providing tank containers for specified routes at fixed freight rates. Spot customer is the one that regularly requests tank container depending on its market situation and quoted freight prices. Tank operator, hence, must have enough empty tank containers at the port of origin to satisfy contract demand while accommodate spot demand when applicable. In addition, due to the imbalance of trade flow, forward and backward movements of the same origin-destination pairs are not equivalent. Some of them have substantial amount of container demand forward and not a single of them loaded back. As a result, empty tank container repositioning is a mandatory to move tank container from import-dominant country to export-dominant country, in order to satisfy customer demand. In case of emergent tank shortage, tank operator typically leases empty tank container on spot basis from open market.

Suppose that the company has m different ports of origins and n different ports of destination. Given P is the set of ports indexed by i and j, where $i = 1,2,3,\ldots..,m$ and $j = 1,2,3,\ldots..,n$. With the aim to maximize overall profit, the model is to determine decision variables as follows

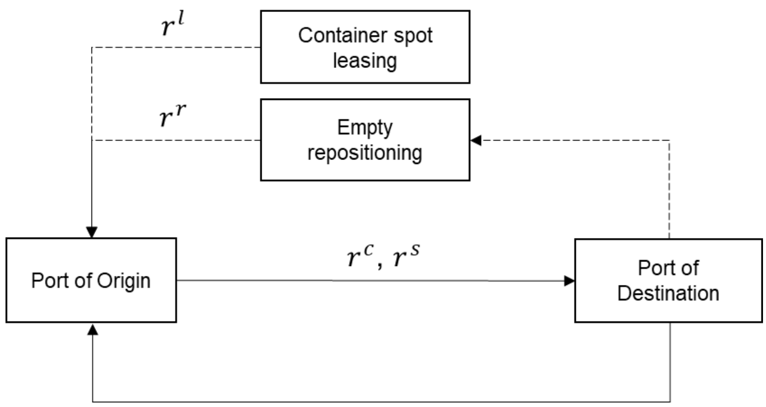

Figure 11 Tank container flow routes in company A operation

- quantity of tank containers that the company can accommodate *contract demand* in each route at specified time rolling period
- quantity of tank containers that the company can accommodate *spot demand* in each route at specified time rolling period
- *repositioning route* as well as *quantity of empty tank container* between international ports and domestic ports that needs to be relocated to accommodate tank container demands
- the needs of container *spot leasing* to accommodate tank container demands

The basic assumptions of the model are stated as follows.

<u>Assumption</u>

- All costs of empty repositioning and profit per tank of both contract and spot customer demands are known. However, in fact, these simplified profits and costs may be subjected to changes mainly due to fluctuation in ocean carrier freight costs caused by global supply chain uncertainty. The model users, thus, should carefully make use of those figures especially in case of forecasting horizon that the freight cost is not be fixed yet.
- There is only single container type and requirement for all customers considered in the model. The fleet is considered as homogeneous. Even though different customers require different specifications, tank containers are literally used interchangeably in real operation.

- The model does not take different type of chemical cargoes into account. The differences in cleaning costs are already calculated in gross profit per tank containers.
- Tank container cleaning and preparation time are negligible in this model. There are reasonably assumed to be included in total lead time.
- The total lead time of tank containers transportation for all origin-destination demand route is totally three weeks. That is, all containers depart the origin would be available at the destination in the next three following weeks.
- The three-week transportation lead time comprises of one-week transit lead time and two-week returning-period lead time.
- The transit lead time is the time required for transporting tank container from port of origin to port of destination. The average transit time for ocean carrier among intra-Asia countries in one week. In reality, transit time could be, nevertheless, prolonged by a consequence of vessel delays as well as port congestions. Hence, the model users need to keep in mind of this simplified assumption of one-week transit lead time.
- The returning-period lead time is the time span required at port of destination to unloading the chemical cargo at consignee plant. The period of free-time in terms of agreement is normally 14 days (2 weeks). Thus, the author assumes that consignee would return tank containers within the free-time period to avoid additional demurrage charges. Having said that, some manufacturers may keep tank containers for longer than that period. Late returning of units then lead to shortage situation of tank containers. Hence, likewise the transit lead time, the model users need to keep in mind of this simplified assumption of two-week returning period lead time.
- Lead time of empty tank container transportation between international ports for all origin-destination route is one week.
- There is no lead time, discretized in week, of empty tank container transportation between domestic ports for all origin-destination route. That is, empty tank container repositioning that departs ports of origin would arrive domestic ports of destination in the same week.

- In this model, there is unlimited supply for spot container leasing from open market. As a matter of fact, however, the spot leasing supply seems to be limited depending on tank container availability of others tank container operator as well as their willingness to lease out the units.
- The container spot leasing is meet immediately in the week.
- The container from spot leasing is return to lessees after the weekly uses and do not count in company fleet inventory.
- Cost of tank container spot leasing is fixed at 1,000$ for the model parameters and there is no difference in spot leasing cost between any of origin-destination routes. In practice, however, the leasing costs vary destination by destination depending on its inbound and outbound market situations.

3.2 Mathematical Formulation

The notations are as below.

Sets

- P is the set of ports indexed by i, j
- R^c is the set of contract demand routes indexed by r^c
- R^s is the set of spot demand routes indexed by r^s
- R^{ri} is the set of empty repositioning routes between international ports indexed by r^{ri}
- R^{rd} is the set of empty repositioning routes between domestic ports indexed by r^{rd}
- R^l is the set of spot leasing routes indexed by r^l
- R^i is the set of empty repositioning routes that utilizes financial incentives indexed by r^i

Parameters

- d_{r^c} is the quantity of tank container demanded in contract demand route r^c
- d_{r^s} is the quantity of tank container demanded in spot demand route r^s

Decision variables

- x_{r^s} is the number of tank containers that accommodate contract demand route r^c
- w_{r^s} is the number of tank containers that accommodate spot demand route r^s
- $y_{r^{ri}}$ is the number of empty tank containers being repositioning between international ports in route r^{ri}
- $v_{r^{rd}}$ is the number of empty tank containers being repositioning between domestic ports in route r^{rd}
- z_{r^l} is the number of spot lease tank containers in route r^l

Objective function

Consider tank container flow from port of origin i to port of destination j at week n. For any i and j, there are container flows in 4 routes which are contracted routes (r^c), spot routes (r^s), empty repositioning routes (r^r), and spot leasing route (r^l). The profit is generated by the number of loaded containers x_{r^c} and w_{r^s}, which accommodate contract and spot customer demands, d_{r^c} and d_{r^s}, respectively. Notice that all contract demand must be fulfilled in tank container operation, thus, x_{r^c} is equal to d_{r^c} by construction in this formulation. Operating costs are incurred from repositioning empty container y_{r^r} and spot leasing containers z_{r^l}. Since the relevant costs are assumed to be linear, the objective function to maximize profit is shown as equation (1)

$$\text{Max } Z = \sum_{r^c \in R^c} \sum_{r^c \in R^c} p_{r^c}\, d_{r^c} + \sum_{r^s \in R^s} \sum_{r^s \in R^s} p_{r^s}\, w_{r^s} - \sum_{r^{ri} \in R^{ri}} \sum_{r^{ri} \in R^{ri}} c_{r^{ri}}\, y_{r^{ri}}$$

$$- \sum_{r^{rd} \in R^{rd}} \sum_{r^{rd} \in R^{rd}} c_{r^{rd}}\, v_{r^{rd}} - \sum_{r^l \in R^l} \sum_{r^l \in R^l} c_{r^l}\, z_{r^l} \qquad (1)$$

where,

- p_{r^c} is the profit per tank container of contract demand in route r^c
- p_{r^s} is the profit per tank container of spot demand in route r^s
- $c_{r^{ri}}$ is the cost of repositioning empty tank container between international ports in route r^{ri}
- $c_{r^{rd}}$ is the cost of repositioning empty tank container between domestic ports in route r^{rd}
- c_{r^l} is the cost of leasing tank container to accommodate demand in route r^l

It is generally agreed that optimization model is concurrently apply together with forecasting data to achieve efficient solution. Having said that, the forecasting of both contract and spot demands are not available in Company A's historical record. Alternatively, financial incentives of empty container repositioning in specific routes are added in objective function as shown in equation (1.1). To be more specific, financial incentives are added for empty repositioning routes that originated from import-dominant ports of which its repositioning destinations tend to witness a shortage situation. This is to guide the tank container inventory stock-up behaviors like actual operation as results of empty repositioning from import-dominant to export-dominant ports.

$$\begin{aligned}\text{Max } Z = &\sum_{r^c \in R^c} \sum_{r^c \in R^c} p_{r^c}\, d_{r^c} + \sum_{r^s \in R^s} \sum_{r^s \in R^s} p_{r^s}\, w_{r^s} - \sum_{r^{ri} \in R^{ri}} \sum_{r^{ri} \in R^{ri}} c_{r^{ri}}\, y_{r^{ri}} \\ &- \sum_{r^{rd} \in R^{rd}} \sum_{r^{rd} \in R^{rd}} c_{r^{rd}}\, v_{r^{rd}} - \sum_{r^l \in R^l} \sum_{r^l \in R^l} c_{r^l}\, z_{r^l} \\ &+ \sum_{r^s \in R^s} \sum_{r^s \in R^s} i_{r^i}\, y_{r^{ri}} \qquad (1.1)\end{aligned}$$

where,

- i_{r^i} is the incentives per tank containers of empty repositioning in specific routes

The objective function is subjected to the following constraints.

Constraints

As for spot customer demand, it is acceptable to partially fulfill if there is not sufficiently available tank container in a particular week. Constraint (2) specifies that, for all spot demand routes, number of tank containers accommodated those demands must be less than or equal to the number of total spot containers demands.

$$w_{r^s} \leq d_{r^s} \qquad \forall\, r^s \in R^s \qquad (2)$$

The conservation of tank container flow is considered as an important constraint in this model. Constraint (3) specifies that, the total number of tank containers that departs port of origin i cannot exceed the tank container inventory at port i. Those outbound tank containers quantity include tank containers that accommodated contract as well as spot demands and empty tank containers that both being repositioned between international ports and domestics ports from port of origin i. The calculation is presented in constraint (4). To ensure the fulfillment of contract demand, the inventory level of tank container at current week should be sufficient to accommodate next week contract demand. In addition, if there is any insufficient of tank container at port i, spot leased tank container is added up. It must be noted that the spot leased tank containers would be returned to the leasee instantly after one-single trip used and do not count in company fleet inventory.

$$a_p^n + \sum_{r^c \in R_{p-}^c} d_{r^c}^{n+1} \leq I_p^n + \sum_{r^l \in R_{p+}^l} z_{r^l}^n - \sum_{r^l \in R_{p-}^l} z_{r^l}^{n-1} \qquad \forall\, p \in P \qquad (3)$$

$$a_p^n = \sum_{r^c \in R_{p-}^c} d_{r^c}^n + \sum_{r^s \in R_{p-}^s} w_{r^s}^n + \sum_{r^r \in R_{p-}^{ri}} y_{r^{ri}}^n + \sum_{r^r \in R_{p-}^{rd}} v_{r^{rd}}^n \qquad \forall\, p \in P \qquad (4)$$

Constraint (5) represents the calculation of inbound tank containers according to the lead time stated in the assumption. That is, there is totally three-weeks lead time for all origin-destination demand routes. As for empty repositioning tank containers, there is one-week lead time for empty tank container repositioning between international ports, while there is no lead time discretized in week for empty tank container repositioning between domestic ports.

$$b_p^{n+3} = \sum_{r^c \in R_{p+}^c} d_{r^c}^n + \sum_{r^s \in R_{p+}^s} w_{r^s}^n + \sum_{r^r \in R_{p+}^{ri}} y_{r^{ri}}^{n+2} + \sum_{r^r \in R_{p+}^{rd}} v_{r^{rd}}^{n+3} \qquad \forall\, p \in P \qquad (5)$$

Due to the fact that, the initial inventory level used in the starting week of the model was retrieved from the tank container fleet status report of the company A at the end of week 40. It should be noted that the retrieved data cannot be used as model input instantly. That is because the system does not only record the inventory, but also others status which do not include in the model, namely, not-arrive-yet tank containers and not-return-yet tank container. From this reason, there is a need in adjustment technique of inventory level in the model using those recorded tank container status. Not-arrive-yet tank container is the tank containers that have already departed from the port of loading but not yet arrive port of destination. Not-return-yet tank container is the tank containers that have already arrived at port of destination but not yet return to the storage depot. The inventory adjustment scheme, as shown in Figure 12, is aligned with the model assumption. That is, not-arrive-yet tank containers would be counted as inventory after passed 3-week lead time. Similarly, not-return-yet tank containers would be counted as inventory after passed 2-week lead time. The adjustment figure of inventory at week n is denoted as c_p^n. Hence, the inventory level at week n is calculated by constraint (6).

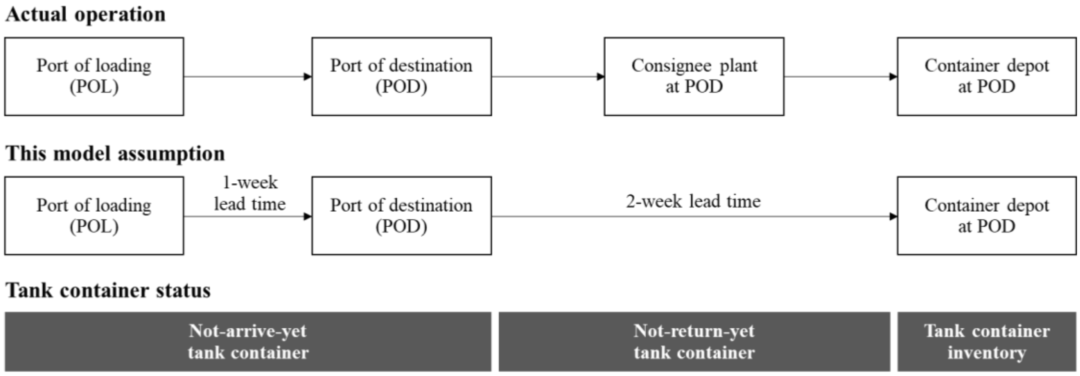

Figure 12 Inventory adjustment scheme

$$I_p^{n+1} = I_p^n - a_p^n + b_p^{n+1} + c_p^{n+1} \qquad \forall\, p \in P \qquad (6)$$

,where

- I_p is the inventory of tank container at port p
- I_p^n is inventory of tank container at any port at week n
- a_p^n is the number of tank container that departs port p at week n
- b_p^{n+1} is the number of tank container that arrives port p at week $n+1$
- c_p^{n+1} is the number of adjust tank container at week $n+1$
- R_{p-}^c is the set of contract demand routes that depart port p
- R_{p-}^s is the set of spot demand routes that depart port p
- R_{p-}^{ri} is the set of empty repositioning routes between international ports that depart port p
- R_{p-}^{rd} is the set of empty repositioning routes between domestic ports that depart port p
- R_{p-}^l is the set of spot leasing routes that return to leasee at port p
- R_{p+}^c is the set of contract demand routes that arrive port p
- R_{p+}^s is the set of spot demand routes that arrive port p
- R_{p+}^{ri} is the set of empty repositioning routes between international ports that depart port p
- R_{p+}^{rd} is the set of empty repositioning routes between domestic ports that depart port p
- R_{p+}^l is the set of spot leasing routes that arrive port p

In addition to those, constraints (7) and (8) may be added to allow the model to behave alike the actual operation. Reason being, for some ports, there are only inbound shipments which are so-called import-dominant ports. Moreover, the empty repositioning from those ports to export-dominant ports do not take place because the inventory level at the port of destination is still sufficient to support demands according to constraint (3). Whereas in actual operation, tank containers that arrived at import-dominant ports would be planned to reposition to export-dominant ports right away after the returns. Thus, it can be said that, unless constraints (7) and (8) are added, tank containers are accumulated at those import-dominant ports which do not reflect the results of actual operations. Constraints (7) and (8) specify that tank containers that arrive at import-dominant ports would be promptly repositioned to designated export-dominant ports at the same week of arrival.

$$y^{n}_{r^{ri}} = b^{n}_{p} \qquad \forall p \in P_{p^{ri}} \qquad (7)$$

$$v^{n}_{r^{r}} = b^{n}_{p} \qquad \forall p \in P_{p^{rd}} \qquad (8)$$

Where,

$P_{p^{ri}}$ = {MOJ, NGO, TYO, UKB, YOK, IWK, SMA, OSA, HPH, }

$P_{p^{rd}}$ = {BKK}

3.3 Computational experiment

The linear programming model is solved using laptop computer model HP ENVY x360 with AMD Ryzen 5 2500U processor and 8.00 GB installed RAM. The model is formulated in Microsoft Excel application in Microsoft Office 365 package. Instead of conventional solver excel add-in, of which variable cell is limited at 200, OpenSolver is used to solve the model to an optimality. OpenSolver (Mason, 2012) is an opensource add-in under Computational Infrastructure for Operations Research (COIN-OR) CBC optimization engine. It is largely compatible with Microsoft Excel with none the variable sizes limitation. Hence, OpenSolver allows users to solve large linear programming model in spreadsheets. In this work, OpenSolver 2.9.3 was used.

Sets of data, namely, records of tank container flows according to contract and spot demands as well as tank container inventory level are required to test the model. Having said that, Company A did not keep the past record of inventory level in its system. Hence, due to that unavailability, the author necessarily uses the inventory data at the point of time that this model is formulated. That is to say, the model is desired to be experimented with company A's 6-months historical data started from October 2020 to March 2021. The data is separated into 6 time periods discretized in week. Each time-period represents each month of business operation. As summarized in Table 3, there are 2,245 parameters of contract demands and 3,570 parameters of spot demands that is going to be tested in this linear programming model.

Table 3 Summary of Company A's historical data used to test the model

	Time period	Month	Year	Demand quantity (Unit: tank container)	
				Contract demand	Spot demand
1	week 41 - week 44	October	2020	409	512
2	week 45 - week 48	November	2020	397	637
3	week 49 - week 53	December	2020	373	727
4	week 1 - week 4	January	2021	311	396
5	week 5 - week 8	February	2021	330	484
6	week 9 - week 13	March	2021	425	814
			Total	2,245	3,570

The model is solved using a rolling horizon approach which is a time-dependent scheduling formulation that solves deterministic model iteratively by moving forward the optimization horizon in each solution step. This approach comprises of three different time horizons namely, scheduling horizon, prediction horizon, and control horizon. Scheduling time horizon is an overall period to be optimized in the model. Prediction horizon is the period that contains decision variables which are going to be solved. Control horizon is the period that the solution has already optimized. It is fixed and use as an input for the next rolling period. In this linear programming model, scheduling time horizon is a period of six-month starting from October 2020 to March 2021. Hence, there are totally six prediction horizons where each horizon represents a single month of data as described before.

The rolling horizon scheme of this model is presented in Figure 13. Firstly, initial parameters of the model, which are contract and spot demands, are established. After that, the first prediction horizon (week41– week44) is solved. The final values obtained from the optimization process are fixed. Subsequently, some data of the next rolling horizon (week45 – week48) are updated using the fixed optimized results from previous. The information required to be updated are spot demand accommodations of the last three weeks and empty repositioning tank containers between international ports of the last week from the previous prediction horizon. These are mainly due the assumption of three-week lead time one-week lead time for customer demands and empty container repositioning between international ports, respectively. The optimization problem is then solved repeatedly until the planning horizon corresponds to the final time period of scheduling time horizon.

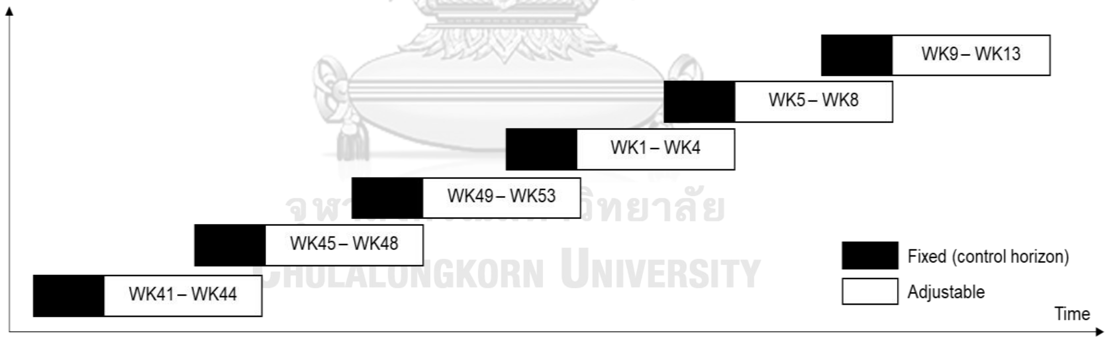

Figure 13 Rolling horizon scheme of the optimization model for chemical tank container management

Table 4 Objective function and constraints used in each model

Notation	Objective Function	Constraints
Model 1	(1)	(2), (3), (4), (5), (6)
Model 2	(1)	(2), (3), (4), (5), (6), (7), (8)
Model 3	(1.1)	(2), (3), (4), (5), (6), (7), (8)

To illustrate behaviors of the optimization model according to the mathematical formulation, three models which occupied different objective function and sets of constraints are experimented separately. The objective function and constraints of each model are presented in Table 4. Model 1 is a conventional model without any regulated constraints. That is, all utilized constraints are related to tank container flow and its conservation. Model 2 is a model that adds tank container repositioning constraints (equation (7) and (8)) to force empty container repositioning from the ports that do not have outbound demands to export-dominant ports. Model 3 utilizes almost the same constraints as Model 2 but applies objective function with financial incentives (equation 1.1) to guide empty container repositioning from ports that do not have outbound demands for inventory stocking purposes at other ports.

3.4 Sensitivity analysis

It is the fact that the developed linear programming model is only a construction of mathematical concepts and equations to describe real business operation scheme. The parameters used for the inputs of constraints and objective function coefficients are very prone to errors in forecasting or even changing circumstances, which cannot be captured by the model. Hence, there is a need in others technique to foresee the effects of changes in parameters on the objective function as well as optimized results.

Sensitivity analysis, also known as post-optimality analysis, is a systematic study of the effects of the changes in parameter on the objective value. It is very useful in dynamic environment. In linear programming solver, there are two separate sensitivity report tables obtained once the optimization process in done. One is the sensitivity report related to constraints of the model. The other is related to decision variable. The value associated with those sensitivity reports are shadow price and reduced cost, respectively.

In this study, the author would make use of shadow price from sensitivity report obtained after the model is solved to the optimized value. The example of sensitivity report on constraint is presented in Table 4. In linear programming, the shadow price is defined as the instantaneous changes in the objective value of the solution at optimum basis obtained by one unit changing of the right-hand side constraint. The allowable increase is the amount of which the objective function coefficient can increase without any effects an optimal value. Likewise, the allowable decrease is the amount of which the objective function coefficient can decrease without any effects on optimal basis.

Chapter 4

Results and Discussion

In this chapter, the obtained results from the model are discussed including (4.1) computational results and (4.2) sensitivity analysis. The computational results present a comparison between actual operational profit and operational profit from the model. On top of that, the exact need of empty container repositioning is examined by means of inventory level at any ports. The differences in outcomes from three models are discussed. In addition, sensitivity analysis presents a useful information from shadow price obtained from sensitivity report once model is solved to the optimal.

4.1 Computational results

The computational results derived from the optimization model literally comprise of contract demand accommodation, spot demand accommodation, empty tank container repositioning between both international and domestics ports as well as spot tank container leasing. In this section, the author would majorly present and discuss on the outcome from those demand accommodations and empty repositioning activities which include but not limited to financial results and inventory level at any ports. From the results, it is clearly seen that each of three models provide different consequences depending on the applied objective function and constraints. Hence, the results from all three models are compared with figures from actual operation.

4.1.1 Financial results

In this optimization model, the objective function is to maximize net profit of chemical tank container business operations. As stated in its equation, net profit is a summation of total profit from demand accommodation subtracted by cost of empty tank containers repositioning and spot leasing. In this part of results and discussion, the author would not only focus on an improvement of net profit, but also emphasize on the differences between every related terms as mentioned earlier.

From the model, there are two sources of profit namely, contract demand accommodation and spot demand accommodation. The optimal results show that all models as well as actual operation give the same figure of the profits from contract demand accommodation, which accounting for 570,557.18 USD. The reason behind this is that there are no constraints regarding to contract demand. Thus, tank container that accommodate contract demand in the models are equal to their parameters as recorded in actual operation which ultimately results in the same amount of profit.

As for spot demand accommodation, the computational results presented in Figure 14 compares spot demand profit between actual operation and model results. The spot demand profit from actual operation during the period of study was 1,403,451.91 USD, whereas the figures from models are 1,303,057.21 USD, 1,335,133.86 USD, and 1,355,022.56 USD for Model 1, Model 2, and Model 3, respectively. Noticeably, all model results are lower than the actual. That is, there are 7.15%, 5.12%, and 3.39% lower compared to actual operation. The monthly profit from spot demand accommodation is portrayed in Figure 15.

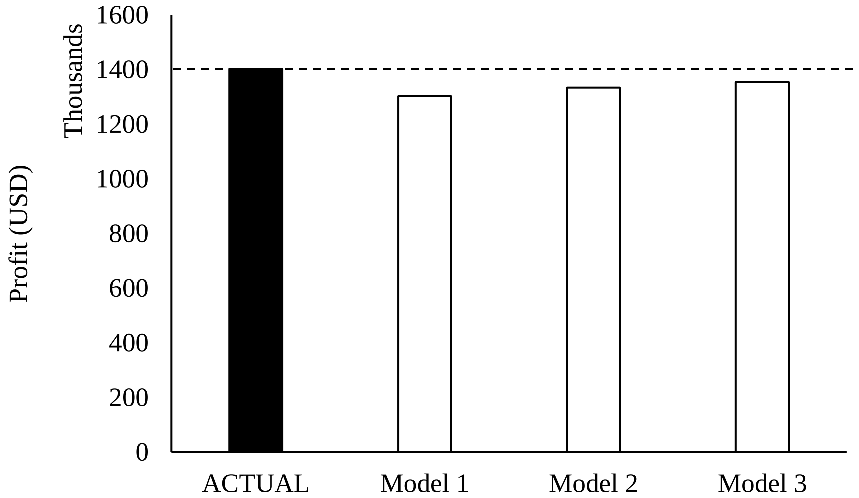

Figure 14 The comparison of spot demand profit from actual operation and model results

There are mainly three reasons that explain why the model results can accommodate lower spot demands comparing with actual operation. Firstly, it is because cost of empty container repositioning to the port of loading is higher than profit of spot demand. So that, it is not worth for the model to allow empty repositioning decision. As presented in figure 16, for instance, costs of empty container repositioning between international ports to Port of KWY are 318.25 and 303.64 USD for HCM-KWY and HKG-KWY routes, respectively. As for domestic ports, it equally costs 215.00 USD to reposition empty tank containers from both INC and KUV ports to the said port. On the contrary, profit of spot demand that departs Port of KWY are 207.28, 147.19, and 175.64 USD, for KWY-KEL, KWY-PGU, and KWY-QDO demand routes, respectively. Obviously, each repositioning routes costs more than spot demand profit. Hence, there is no empty container repositioning to the port of KWY. As a result, the model cannot accommodate spot demand from Port of KWY to those destination ports because tank container is not sufficient. This circumstance, in addition, causes an effect on the next demand routes. That is, if there is no flow of tank containers in KWY-QDO route, spot demand route originated at Port of QDO would not be accommodated as well. Having said that, adding repositioning constraints as well as financial incentive can mitigate this problem. Reason being, for the former, it forces empty repositioning from ports that do not have outbound demand to other ports that may needs tank containers. While, for the latter, it made the model to realize more profitable figures which promotes empty container repositioning for the route that have incentives, as an example presented in figure 17. Once repositioning is taking place, there is now enough tank container at the ports. Spot demands are then thoroughly be accommodated. From this explanation, model 3 which occupied both repositioning constraint and financial incentives added in objective function give the highest spot demand profit compared to others model.

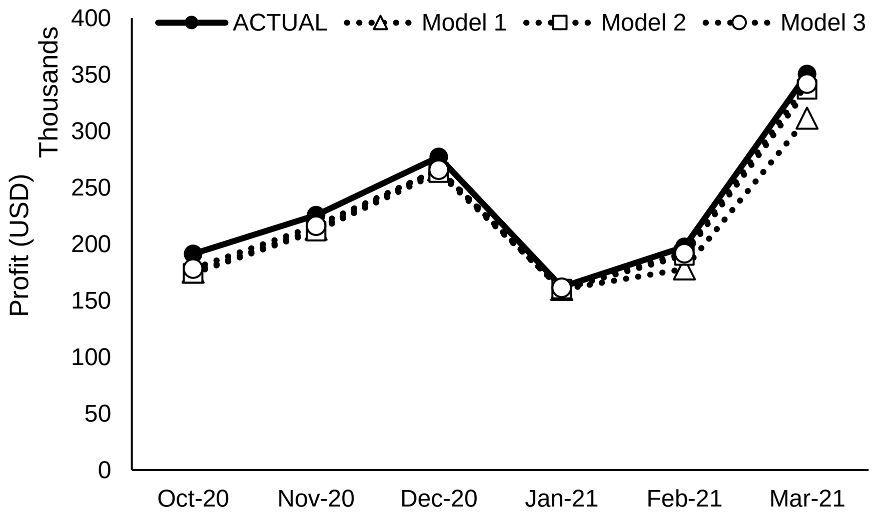

Figure 15 The comparison of monthly spot demand profit from actual operation and model results

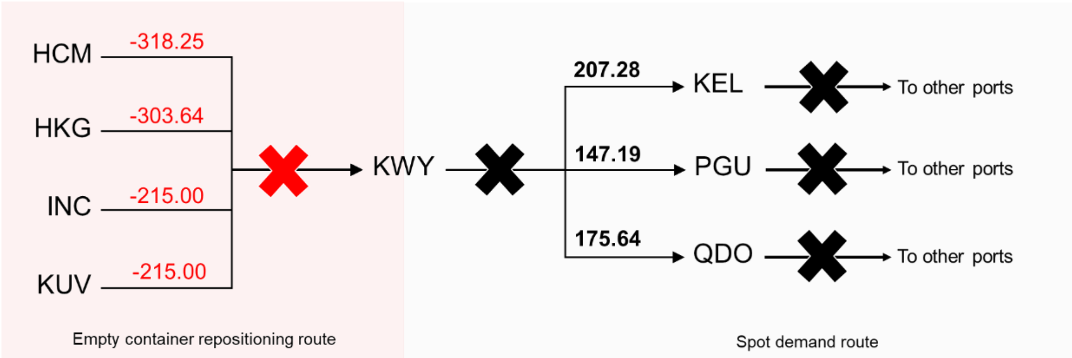

Figure 16 Demonstration of a consequence from lower spot demand profit than empty container repositioning cost on spot demand accommodation

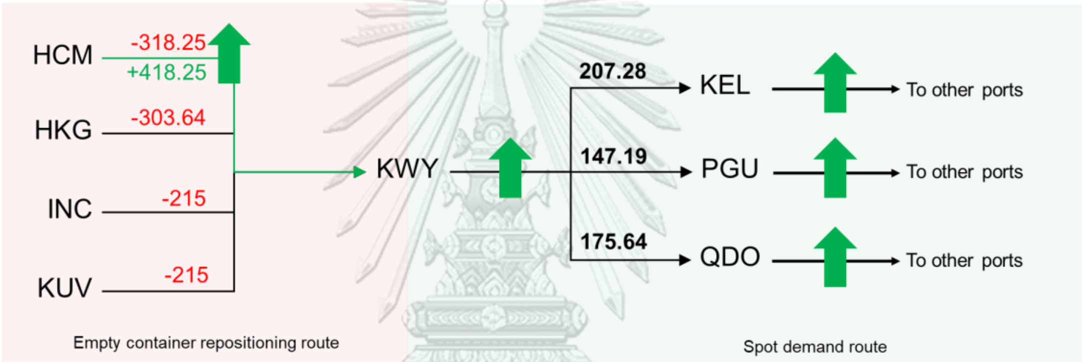

Figure 17 Demonstration of a consequnce from added fiancial incentives on spot demand accommodation

Secondly, the model cannot recognize future spot demand that needs empty container repositioning to support in the starting week of the next rolling horizon period. The reason behind this is that a constraint related to tank container flow merely takes future contract demand into account. In fact, spot demand accommodation is one of decision variables in the model. it is ineligible to include spot demand parameters of next rolling horizon window with a previous using recent in-placed constraints. The example of this case is BLW-USN spot demand route. Normally, in actual operation, inbound tank containers at Port of BLW are lower than outbound demands. Thus, empty tank containers are repositioned domestically from Port of JKT to Port of BLW in an attempt to accommodate spot demands. Nevertheless, from the reason described above, tank containers are not repositioned to support spot demand in that route at the first week of rolling horizon. Figure 18 exemplifies the comparison of spot demand accommodation of BLW-USN route between actual operation and results from Model 3. It shows that the model could not fully accommodate spot demand in week 49, week 5, and week 9. All the mentioned weeks are the starting week of each rolling horizon. For others starting week, i.e., week 41 and week 45, spot demand is fully accommodated because inbound tank containers are fortuitously greater than outbounds. There is, thus, a sufficient tank container inventory to support spot demand needs. It can be noticed that additional empty repositioning constraints as well as financial incentives are not resided in this demand route. Therefore, they cannot mitigate this circumstance of unforeseen spot demand.

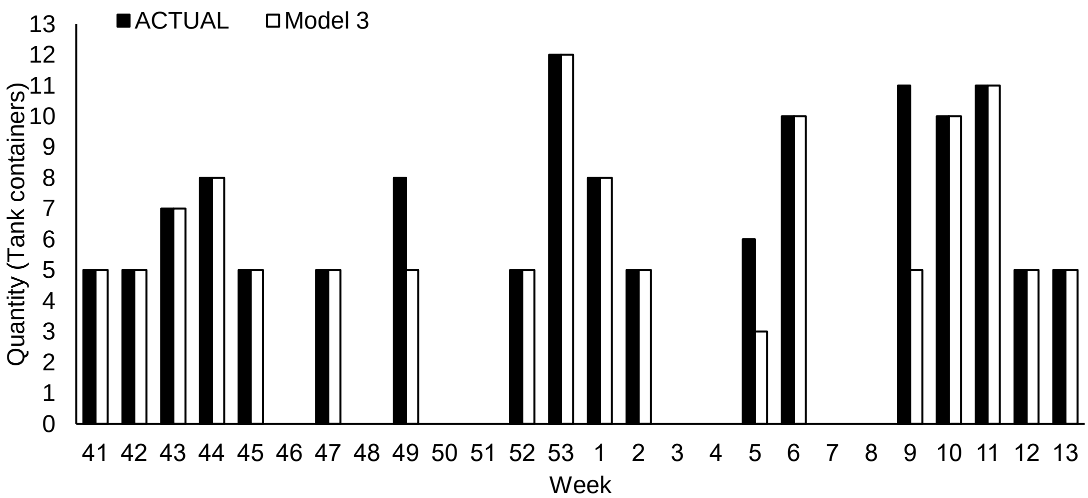

Figure 18 The comparison of Spot demand accommodation in BLW-USN route between Model 3 result and actual operation

Thirdly, the model does not allow tank containers to be picked-up at different ports of loading. Once there is a shortage and no tank containers are repositioned to the ports, the spot demand then cannot be accommodated. In actual operation, however, tank containers at some ports, i.e., Port of PUS, Port of KWY, and Port of USN, are used interchangeably. These three ports are, in fact, located not quite far from each other. So that, if there is insufficient of tank containers at Port of KWY, some shipments are desired to utilize tank containers that store at Port of PUS instead although it incurs additional trucking costs.

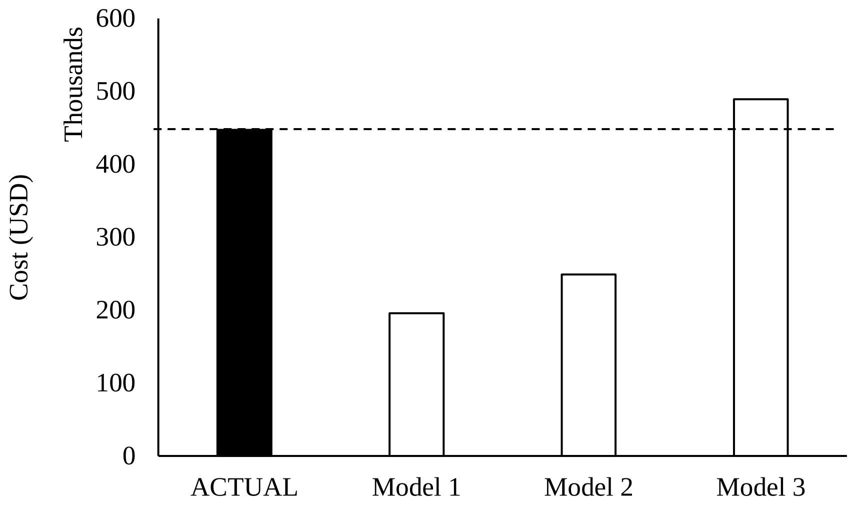

Figure 19 The comparison of empty repositioning cost between international ports from actual operation and model results

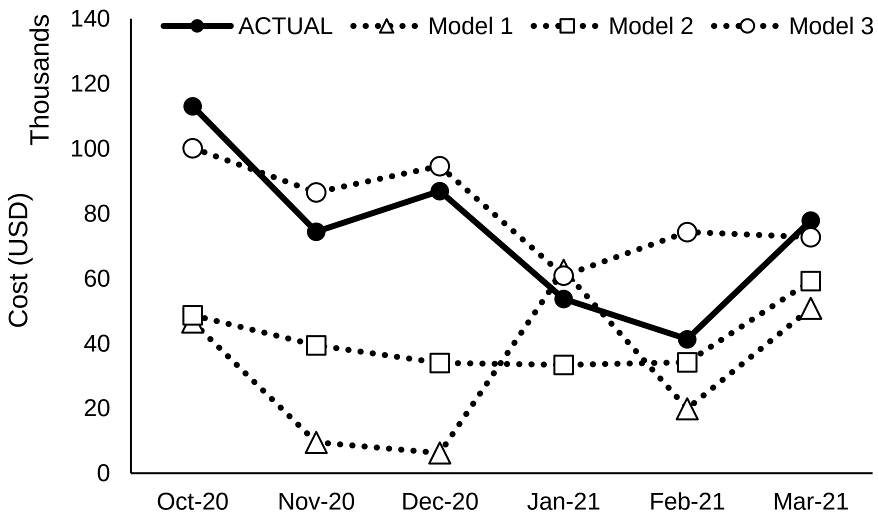

Figure 20 The comparison of monthly empty repositioning cost between international ports

Turning to the terms that related to costs in objective function, figure 19 compares cost of empty container repositioning between international ports from actual operation and model results. It illustrates that figure from actual operation during the period of study was 447,203.23 USD, whereas those from models are 195,620.45 USD, 253,933.24 USD, and 502,938.60 USD for Model 1, Model 2, and

Model 3, respectively. It can be noticed that cost of empty repositioning between international ports from Model 1 is significantly reduced to remain at 43.74% of actual operation costs. This number from Model 2 is, in the same way, decreased to stand at 56.78% of actual. An increase in figure of Model 2 compared to Model 1 is owing to additional constraints that promote empty repositioning from all Japan Ports as well as Port of HPH to Port of PUS. These results imply that Company A is possibly no need that much of empty container repositioning to accommodate spot demand. An excessive quantity in actual operation might be due to inventory stock-up purpose at designated ports. Tank containers are regularly repositioned from ports that do not have outbound demand to ports that that tend to witness a shortage situation. In this case of Company A, most of tank containers were intentionally repositioned to Korea ports, especially Port of PUS. From these arguments, to guide behavior of the model, financial incentives are added in objective function of Model 3 majorly for empty repositioning routes that departs those import-dominant ports, i.e., Port of HCM, Port of HUA, and Port of HKG, to Korea ports. As a result, Model 3 results in 12.46% greater in empty container repositioning cost between international ports than actual operation. An increase of the cost is due to added financial incentives. That is those figures suggest the model that empty repositioning activity would allow the objective function to have positive term in addition to its own cost which is a negative one. This lets the model to recognize more profit and then strongly promote empty repositioning between international ports. Although the cost is slightly overestimated, monthly results from Model 3 are perceptibly correlated with actual operation, as portrayed in Figure 20. So, it can be said that Model 3 of which occupy additional repositioning constraints and financial incentives, is the best model to describe operational decision regarding empty container repositioning between international ports.

As for empty repositioning between domestic ports, result from models and actual operation are compared in Figure 21. It illustrates that figure from actual operation during the period of study was 174,150.70 USD, whereas those from models are 144,873.3 USD, 145,792.50 USD, and 100,337.20 USD for Model 1, Model 2, and Model 3, respectively. It can be noticed that cost of empty repositioning between domestic ports from Model 1 is declined by 16.81% compared to actual operation. The figure from Model 2 is reduced by 14.43%. The difference between these numbers is owing to additional repositioning constraints that stimulate empty repositioning from Port of BKK to Port of LCH and Port of KUV to Port of KWY. As for Model 3, empty repositioning cost between domestic ports is sharply reduced by 42.28%. This is because Model 3 utilizes objective function that added financial incentives for some empty repositioning routes between international ports as mentioned earlier. Importantly, those international routes have the same port of destination as domestic routes. For instance, Port of KWY has both HCM-KWY and HKG-KWY for international routes as well as KUV-KWY and INC-KWY for domestic routes. So that, while added financial incentives promote empty container repositioning between international ports, inventory has been stocked up at the port of destination. Consequently, there is no needs in empty container repositioning from elsewhere to support spot demand accommodation according to tank container flows and conservation constraints. In other words, it inhibits empty container repositioning between domestic ports which then leads to a decrease in the relevant costs.

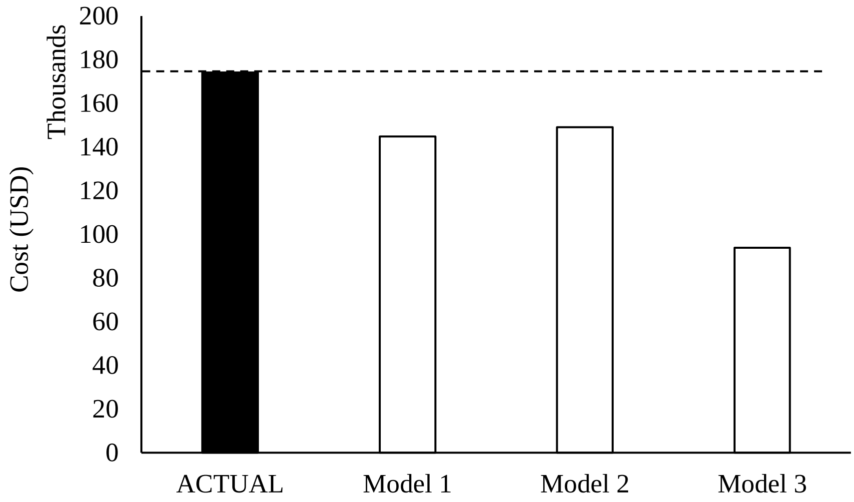

Figure 21 The comparison of empty repositioning cost between domestic ports from actual operation and model results

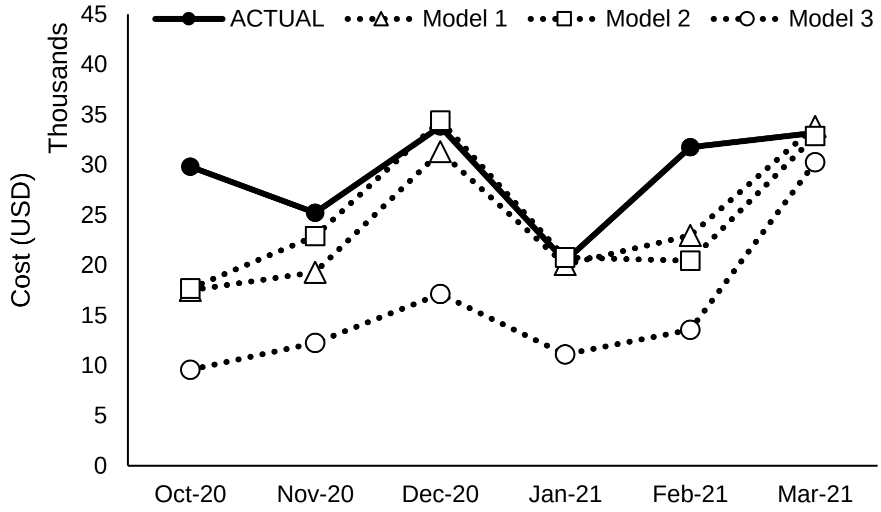

Figure 22 The comparison of monthly empty repositioning cost between domestic ports

A summation of profit from both contract as well as spot demands and total empty repositioning costs leads to net profit results. It should be noted that net profit is calculated by objective function of the model. Importantly, as for Model 3 which utilizes the objective function that adds financial incentives for some empty container repositioning routes, net profit calculation does not take the value from those incentive terms into account. Reason being, the incentives are added to only guide behavior of the model and not considered as income for realistic operations. It can be said that, for all model, net profit is calculated using equation (1) in Chapter 3, regardless which objective function is used.

Computation results presented in Figure 23 compares total net profit between actual operation and all model results. The net profit from actual operation during the period of study was 1,211,718.27 USD. As for the models, the net profits are 1,472,120.64 USD, 1,446,702.76 USD, and 1,281,498.86 USD for model 1, model 2, and model 3, respectively. From these figures, it is clearly seen that operational results obtained from the model generate better net profit than actual operation. Although spot demand profit from the model is lower than actual operation, total net profit still stands above due to a gradual decrease of total cost of empty container repositioning. That is to say, the net profit derived from Model 1, Model 2, and Model 3 are 21.49%, 19.39%, and 5.76% greater than net profit from actual operation, respectively.

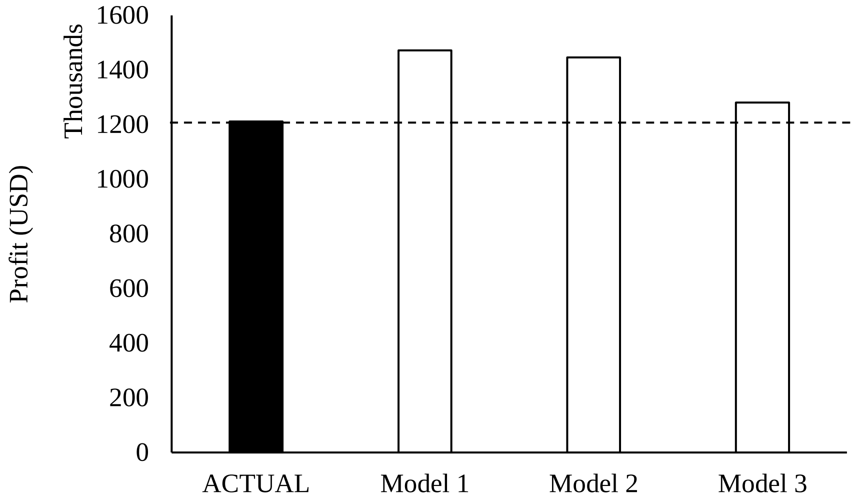

Figure 23 The comparison of total net profit from actual operation and model results

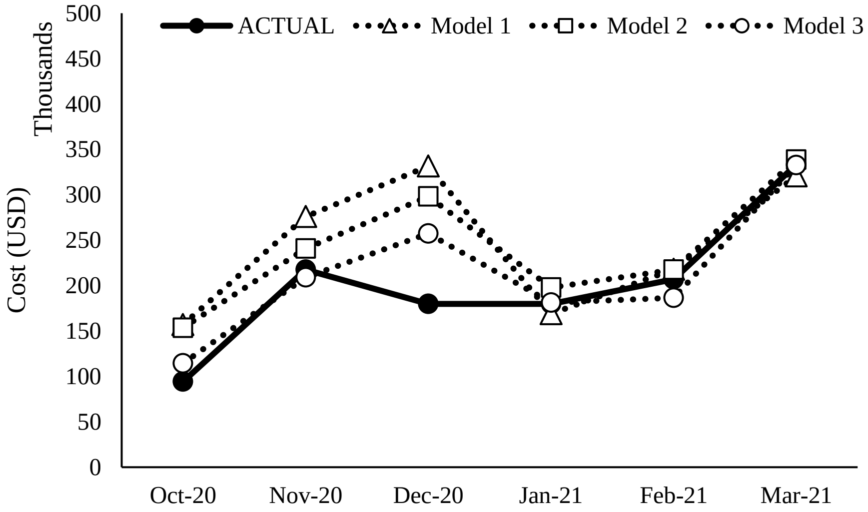

Figure 24 The comparison of monthly net profit from actual operation and model results

4.1.2 Tank container inventory level

Inventory level of tank containers is an ultimate result of demand accommodation and empty container repositioning decisions. Thus, instead of demonstrating all spot demand accommodation and empty repositioning results from the model, inventory level at ports is examined. The related information of those decision variables would be demonstrated where relevant. From the model results, it is an evidence that additional repositioning constraints and financial incentives have a great contribution to inventory level of each model results. In this section, ports that relate to those added terms are exclusively discussed. Figures of inventory level at any ports from each model results are provided in Appendices.

Starting with import-dominant ports with repositioning constraints, Port of BKK is selected as an example. Inventory level at mentioned port obtained from the models are presented in figure 25. It demonstrates that additional repositioning constraints do have a consequence on behaviors of the model. That is, for Model 1 without those constraints, inventory level at Port of BKK increase gradually from 0 at week 41 of 2020 to almost 120 tank containers at week 7 of 2021. After that, it starts to witness a decrease because of domestic empty container repositioning to Port of LCH at week 7 and week 11. The final inventory level stands at 60 tank containers. From this result from Model 1, there are excessive amounts of tank containers stored at Port of BKK. That is because there is no spot demand, which originates from this port, to be accommodated. Figure 26 presents quantity of outbound and inbound tank containers at the said port in actual operation. This is an evidence that over the period of study, there is only tank container flow into Port of Bangkok with no historical outflows. Hence, it is unnecessary to keep stock at Port of BKK. This indicates a possibility of empty container repositioning from Port of Bangkok to accommodate spot demand at others port. In fact, there is only one route of empty repositioning route that departs Port of BKK which is BKK-LCH route. Additional repositioning constraints are then added to force empty container repositioning of that domestic route. Consequently, it is obviously seen that Model 2 which adds repositioning constraints have considerably low inventory level compared to Model 1. Model 3 give the same result as Model 2 because BKK-LCH repositioning route has no financial incentives. The movements of tank container flows from those models are performed more alike actual operation as noticed from a comparison between their inventory levels and actual operation. To this point, it can be said that adding repositioning constraints allow the model to prevent unnecessary inventory costs at Port of BKK. In addition, it appropriately stimulates the model to behave like actual historical operation. Thus, it would be an useful model technique to use in operational planning regarding inventory stock at Port of BKK and BKK-LCH empty repositioning route.

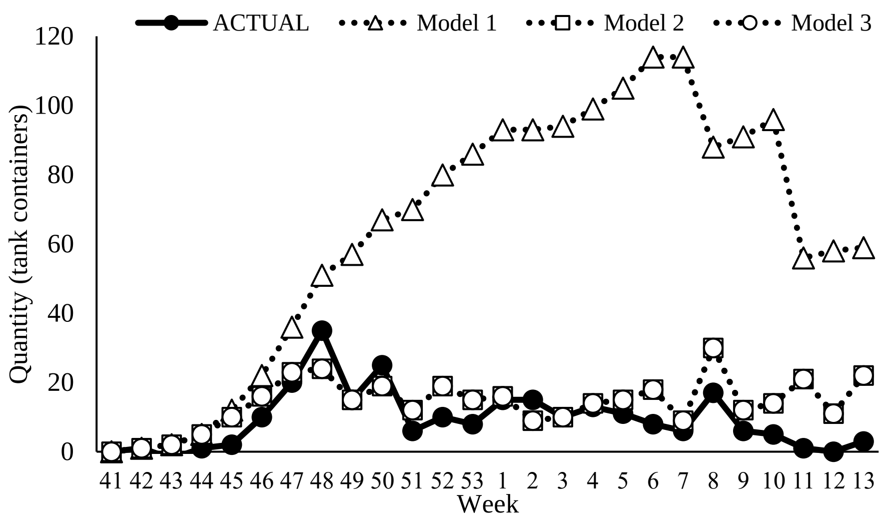

Figure 25 Inventory level at Port of BKK

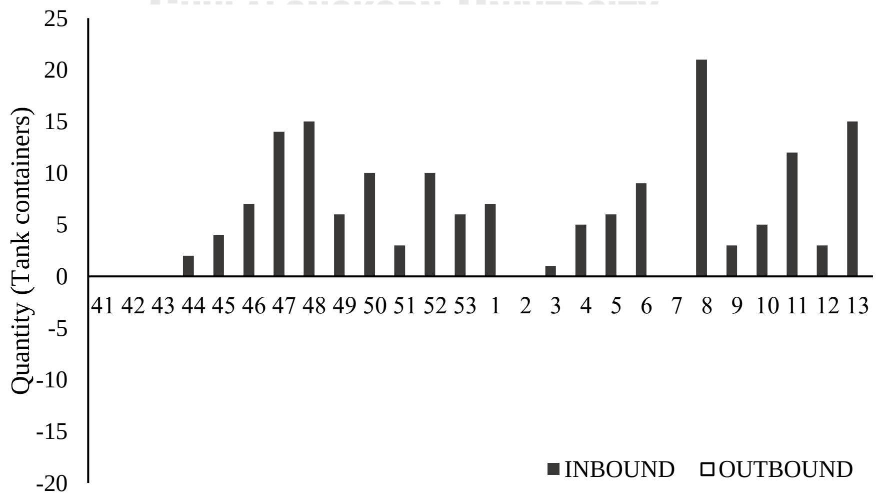

Figure 26 Inbound and outbound demanded tank containers at Port of BKK

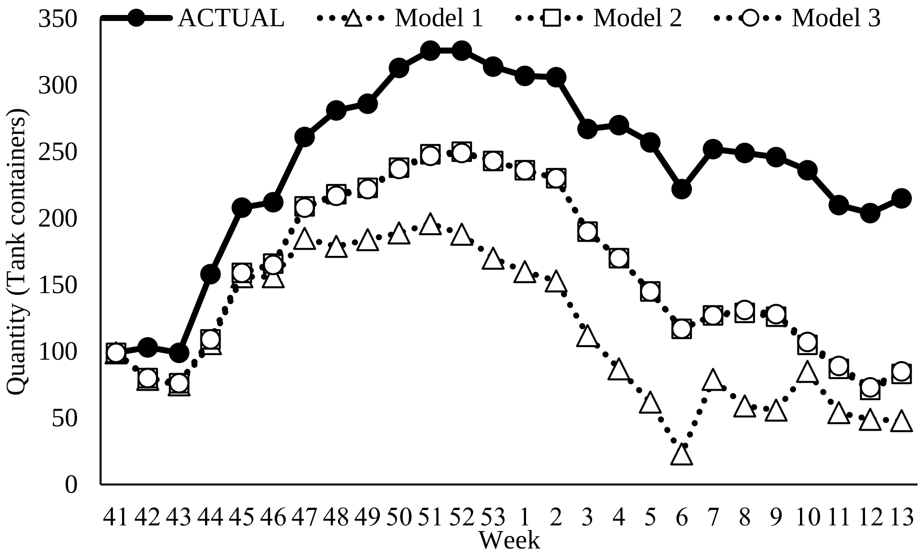

Figure 27 Inventory level at Port of LCH

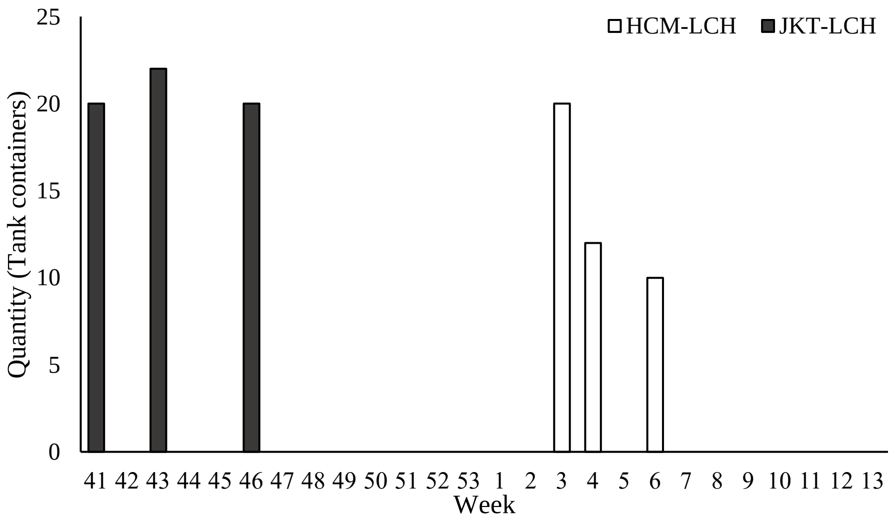

Figure 28 Empty container repositioning from Port of HCM and Port of JKT to Port of LCH

Moving to Port of LCH, which is a destination of an only empty repositioning route from Port of BKK, inventory level from model results and actual operation are shown in Figure 27. It illustrates that Model 1 results in lower inventory level compared to actual operation. In fact, even Model 2 and 3 which utilize additional repositioning constraints that promote empty repositioning from Port of BKK to PORT of LCH, inventory level at Port of LCH is still lower than actual. This is because, in actual operation, there are tank containers that repositioned from other ports, namely, Port of HCM and Port of JKT, apart from Port of BKK to support spot demand accommodation at Port of LCH. As presented in Figure 28, total 62 tank containers are repositioned from Port of JKT in week 41, 43, and 46 of year 2020. There are, in addition, 42 tank containers repositioned from Port of HCM in week 3, 4, and 6 of year 2021. These empty repositioning activities make inventory at Port of LCH up to 326 tank containers at week 52. At the end of period, actual inventory stands at 215 tank containers, while the figure from Model 2 and 3 are only 85 tank containers. It could be highlighted that although the models result in lower inventory level of tank containers, spot demand which originates from Port of LCH is almost fully accommodated. To be exact, there are only 2 out of 415 tank container quantity of spot demand than cannot be accommodated owing to constraint limitation as described in the section related to profit from spot demand accommodation in financial results. To this point, it can be said that the quantity of empty container repositioning from Port of BKK to Port of LCH is sufficient to support demands. Hence, there is no needs of empty tank containers from other ports to Port of LCH. So that, Company A should arrange those 104 tank containers to other destination instead. These could help the company to reduce unnecessary empty repositioning costs as well as increase chances of sales in another trade routes.

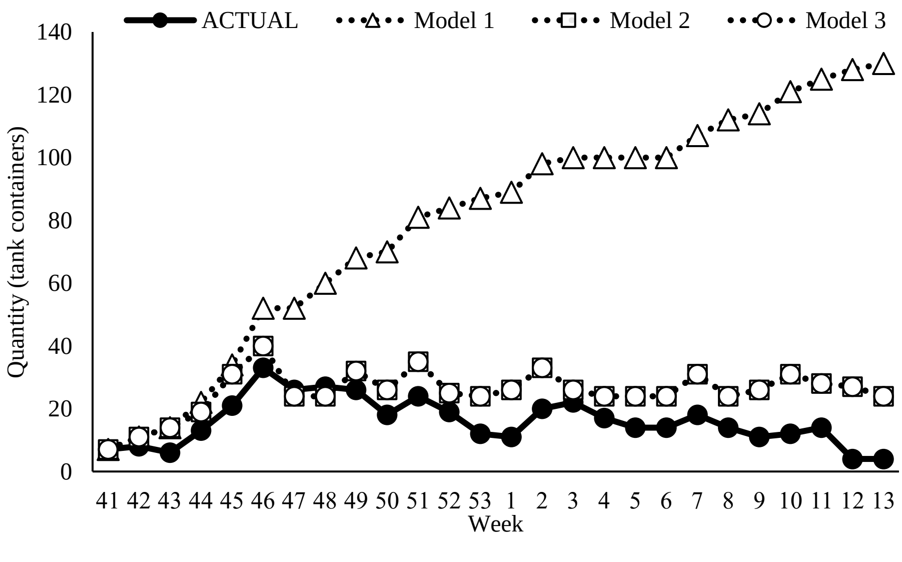

Figure 29 Inventory level at Port of UKB

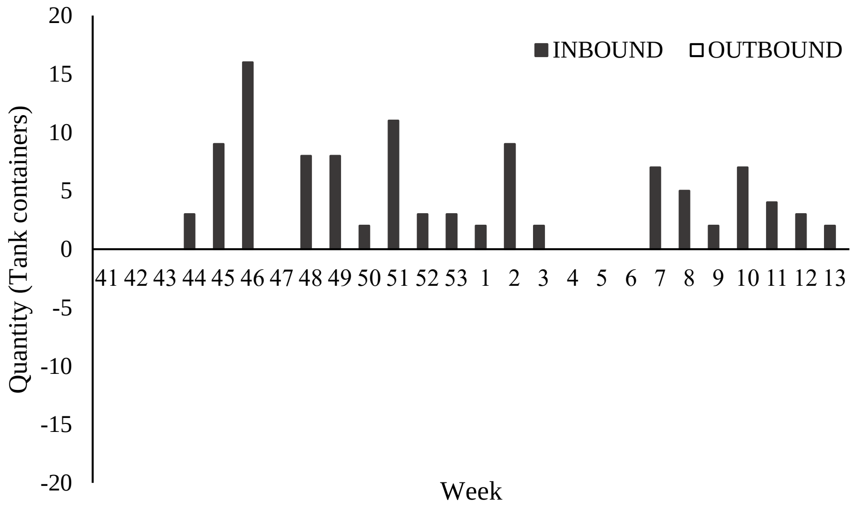

Figure 30 Inbound and outbound demanded tank containers at Port of UKB

While inventory level at Port of BKK provides a good example for an effect of additional repositioning constraints on empty repositioning between domestic ports, inventory level at Port of UKB illustrate the same consequence on empty repositioning between international ports. As illustrated in Figure 29, result of inventory level at Port of UKB from Model 1 continuously increase from 7 tank containers at starting week to reach a level of 130 tank containers at the end of rolling horizon. This scenario implies that empty tank container repositioning from Port of UKB to others port does not take place as an outcome from Model 1. Literally, there is only one route which is UKB-PUS route. The reason behind this is that Port of PUS is not yet experiences a shortage of tank containers. In fact, empty repositioning cost from UKB port or even all Japan ports to Port of PUS are relatively high compared to the costs from other ports, such as Port of HCM and Port of HPH. Once there is a shortage, tank containers from those ports thus have a priority to be repositioned to Port of PUS. However, Port of UKB does not have outbound demand, as an evidence portrayed in Figure 30. So, tank containers are not kept at the said port but plan to reposition to Port of PUS after consignee uses in actual operation. Additional repositioning constraints are applied in the model to force empty container repositioning between international ports on UKB-PUS route. As a result, Model 2 and Model 3 result in lower inventory level compared to Model 1 owing to outbound empty repositioning.

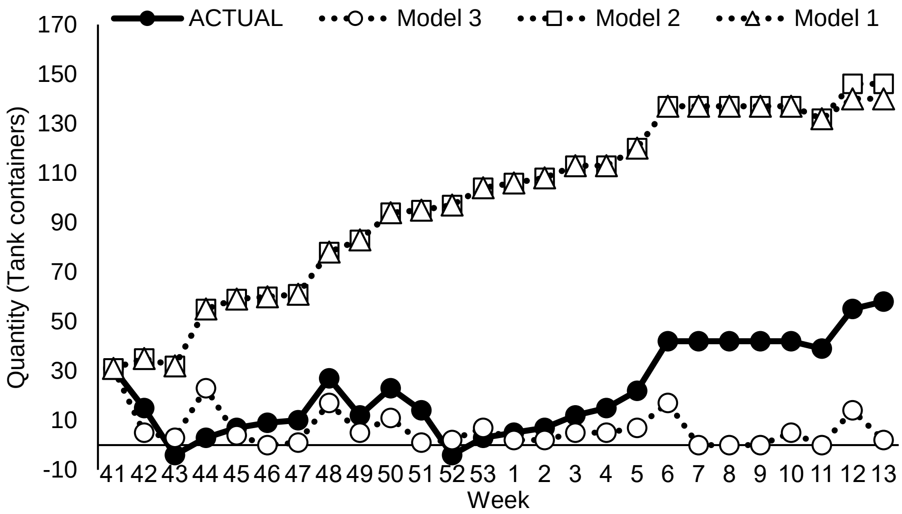

Figure 31 Inventory level at Port of HUA

For some import-dominant ports, additional repositioning constraints are not added in the model although there are no outbound demands. That is because there are more than one empty repositioning routes that depart those ports. For instance, in case of Port of HUA, empty tank containers are moved to either Port of PUS or Port of USN. Furthermore, there are also spot demand tank containers that originate from Port of HUA although those quantity are quite small compared to inbound tank containers. Hence, the model cannot be formulated by particularly force empty repositioning from Port of HUA to any one specific port. So that, financial incentives are utilized to guide empty repositioning behavior of those routes which ultimately result in difference of inventory level among models with the used of different constraints and objective function. That is, as shown in Figure 31, Model 1 result in high level of inventory without any decreases from empty containers repositioning as same as Model 2 that added repositioning constraints. The inventory builds up from 31 tank containers to the maximum level of 146 tank containers at the end of rolling horizon since none of empty containers are repositioned in both HUA-USN and HUS-PUS route. The reason behind this is that Port of USN normally rely on empty containers from Port of HCM which has lower cost of repositioning. As for Port of PUS, there are already piles of tank container stock that repositioned from Port of

HPH as well as all Japan ports as stipulated by additional constraints. Empty container repositioning to Port of PUS is, thus, not required. Having said that, inventory level from Model 1 and Model 2 do not reflect the same trend as actual operation. In addition, it is not reasonable to have loads of tank container inventory at the ports which do not have outbound demands. Financial incentives are then functionally added in objective function to promote empty container repositioning from Port of HUA. As an optimal result obtained from Model 3, inventory level is comparatively low compared to others model. Importantly, it behaves correlatedly with actual operation. From this evidence, it can be said that added financial incentives can guide the model to behave alike actual operation. Apart from Port of HUA, other port that adds financial incentives and experience the same trend of outcome is Port of HKG.

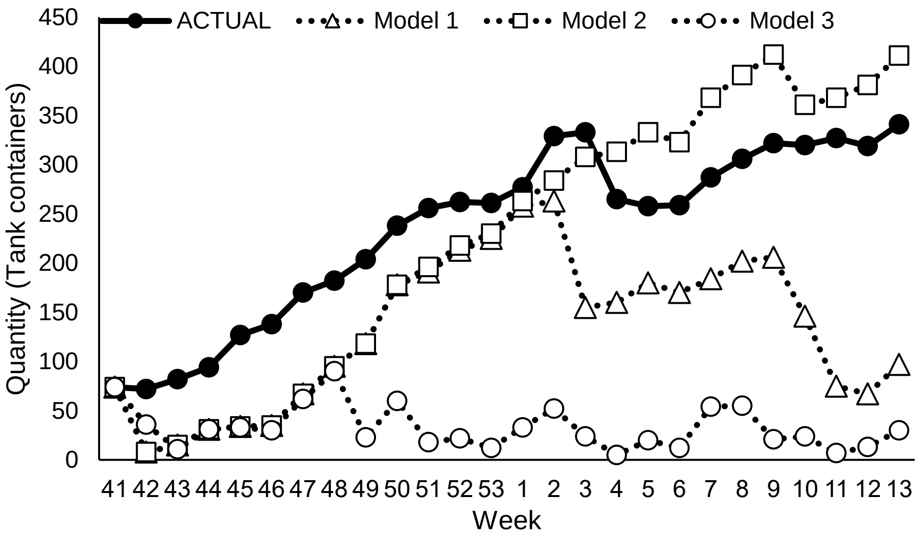

Figure 32 Inventory level at Port of HCM

Financial incentives are also added for empty repositioning routes that originated form Port of HCM, i.e., HCM-PUS, HCM-USN, and HCM-KWY. The result of inventory level at Port of HCM presented in Figure 32. It illustrated that all models behave differently according to their occupied constraints and objective function. That is, inventory level of Model 1 expresses an upward trend to be accumulated at 263 tank containers at week 2 of year 2021. After that it sharply decreases to 155 tank containers owing to outbound empty repositioning at week 2 of year 2021 and further drop to 75 tank containers because of the same reason at week

10 and 11. Those tank containers are majorly repositioning to Port of PUS. As for Model 2, inventory level is relatively high because there is not that much empty container repositioning compared to Model 1. Reason being, Port of PUS already has loads of containers from other ports which are forced by additional repositioning constraints. The quantity is sufficient to support spot demands. Once financial incentives are added, empty container repositioning from Port of HCM is thoroughly promoted as evidenced from low inventory level of Model 3 result. Having said that, none of the model is result in the same operational trend as actual operation. There are two main reasons that can explain this outcome. Firstly, storage cost as well as repair and maintenance costs at Port of HCM is cheaper than Port of PUS or even others Korea ports, due to the economic nature of countries. Port of PUS do not immediately require tank container because of the shortage. So that, it is sensible for Company A to do repair and maintenance jobs then store those well-prepared tank containers at Port of HCM instead of Port of PUS. While those costs are not included in the formulation, the model thus desire to have empty repositioning to Port of PUS, especially when financial incentives are added, which results in lower inventory than actual. On top of that, there are other sources of demands from other business units which do not include in the model. Those neglected demands are tank containers for round-trip and leasing purposes. Round-trip unit is a dedicated container fleet to specific origin-destination route under agreed terms. Leasing unit is tank containers that lease out by customers to use under their own operations. Those units do not relate to network of tank container flows in the model.

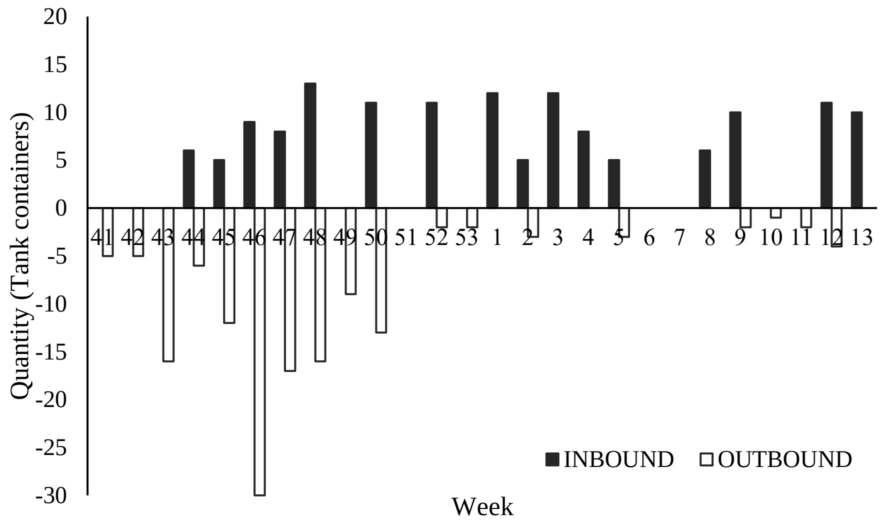

Figure 33 Inbound and outbound demanded tank containers at Port of USN

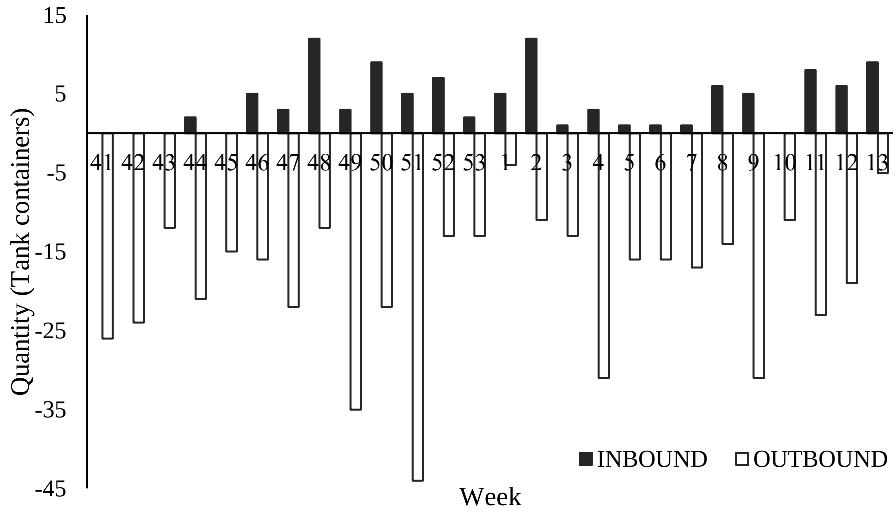

Figure 34 Inbound and outbound demanded tank containers at Port of KWY

It can be observed that inventory level at Port of HCM from all model results sharply plummet at the first week of rolling horizon. This stems from instant empty container repositioning to Port of KWY and Port of USN. Tank container flows at Port of KWY and Port of USN are presented in Figure 33 and Figure 34, respectively. The charts illustrate that there are more outbound tank containers then inbound tank containers. Especially, for the Port of KWY, outbound demands were around 26 tank containers per week while inbound demands were only 4 tank containers per week in average. These are evidence of the needs in empty container repositioning for those ports. Inventory level at Port of KWY and Port of USN are shown in Figure 35 and Figure 36, respectively. It can be noticed that inventory level calculated using actual operation of both ports are expressed in negative values. This owing to the fact that tank container inventory at Port of KWY and Port of USN are not sufficient to accommodate spot demands. The company then necessarily desired to arrange trucking to pick-up tank container at Port of PUS for some shipments. As presented in Figure 37, there are 231 out of 717 tank containers that has been picked-up at Port of PUS and truck to Port of KWY for exporting purpose between the period of study. In case of Port of USN, as depicted in Figure 38, there are 128 out of 276 tank containers that has been picked-up at Port of PUS. Although those operational activities could solve shortage situation at the said ports, additional charges were incurred. That is, it costed 127 USD and 97 USD per tank container picked-up at Port of PUS to move to Port of KWY and Port of USN, respectively. The incurrence of additional trucking costs means that the company has failed to reposition empty tank containers to Port of KWY and Port of USN to support demands at the right time in the right quantity. Having said that, the model developed in this work can use to mitigate the problem. That is, it enhances empty container repositioning from Port of HCM to Port of KWY as well as Port of USN. As seen from the model results depicted in Figure 35 and 36, tank container inventory at both ports are maintained at appropriate level. Importantly, those figures are no longer presented in negative values due to the shortfalls. Hence, it can be said that using optimal result from the model helps the company to effectively plan empty container repositioning to Port of KWY and Port of USN. By doing this, it could save almost 38,553 USD of extra trucking costs that arrange to pick-up tank containers at another port. This would, in addition, increase profit per tank container of spot demands which originates at those ports.

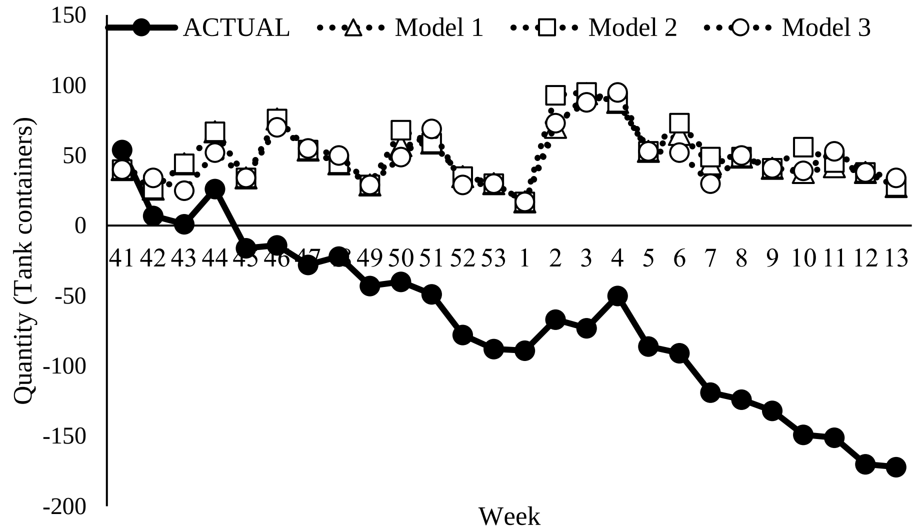

Figure 35 Inventory level at Port of KWY

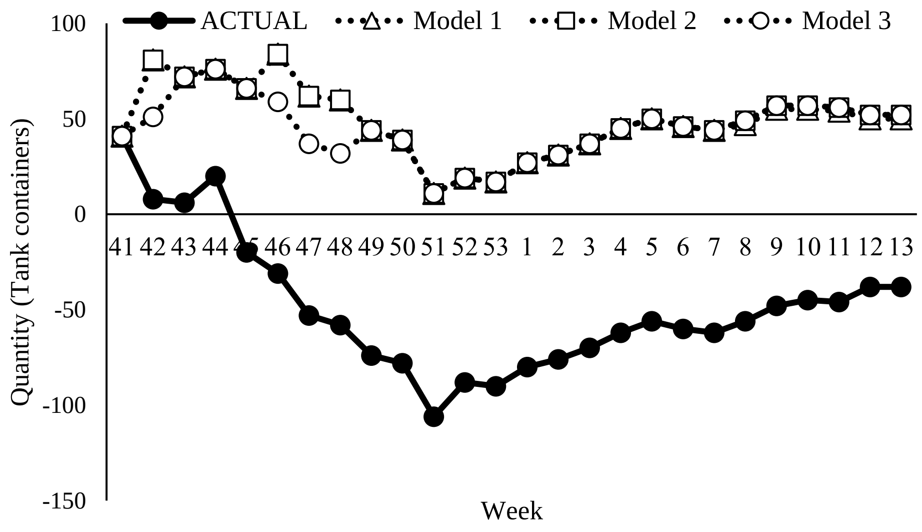

Figure 36 Inventory level at Port of USN

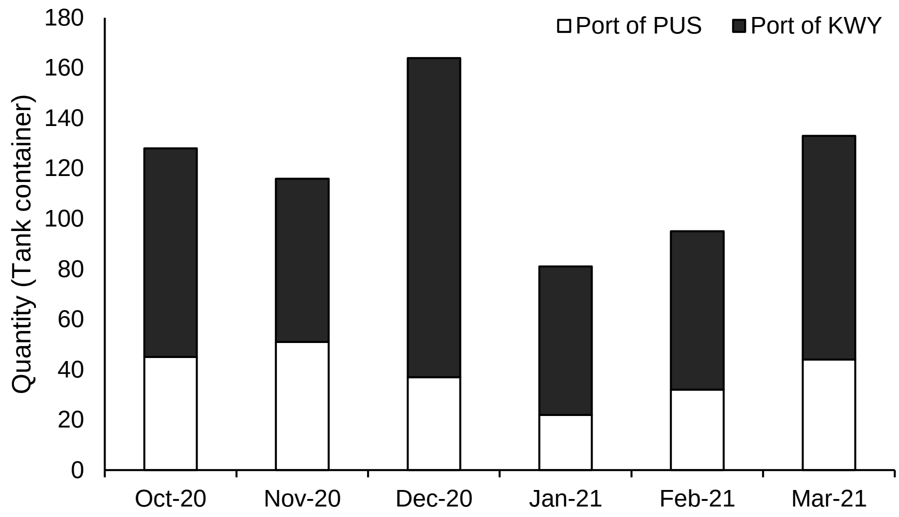

Figure 37 Pick-up ports of demanded tank containers that originate from Port of KWY

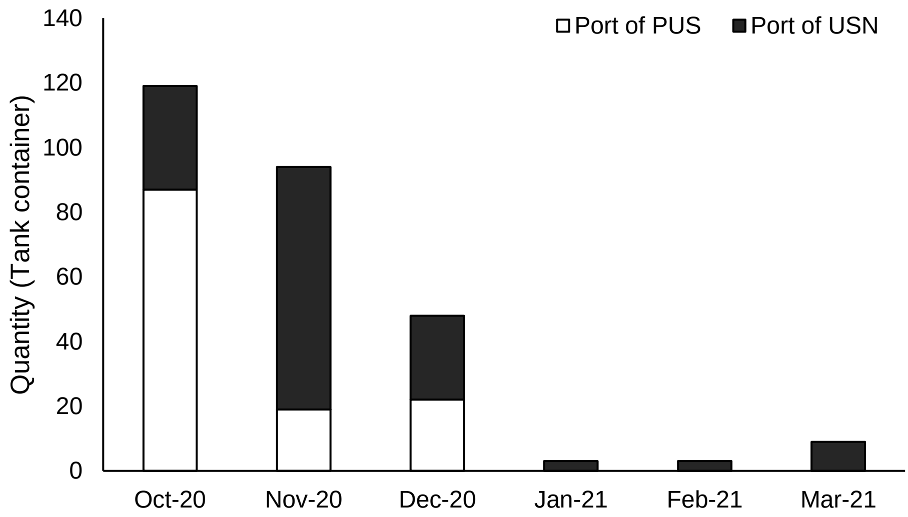

Figure 38 Pick-up ports of demanded tank containers that originate from Port of USN

Apart from Port of KWY and Port of USN, Port of PUS is also a major destination of empty tank container repositioning. As portrayed in Figure 39, average weekly outbound container from Port of PUS was 62 tank containers, whereas an average magnitude of inbounds was only 34 tank containers. Obviously, there is a need of inbound empty container repositioning approximately 30 tank containers per week to support demand at Port of PUS. Figure 40 presents a comparison between inventory level of actual operation and model results. It illustrates that all models result in lower inventory level compared to actual operation. Among all models, Model 1 gives the lowest inventory level along the period of study. That is because it does not include additional repositioning constraints as well as financial incentives. Once those terms are added, inventory level increase gradually as consequences of empty container repositioning to Port of PUS. By way of explanation, addition repositioning constraints promote empty container repositioning from all Japan ports and Port of HPH to Port of PUS. Financial incentives, in addition, stimulate those activities from Port of HCM. It can be noticed that Model 3 still result in lower inventory level than actual operation although tank containers are majorly forced to be repositioned to Port of PUS by additional constraints and financial incentives. This is because, in real operation, tank containers that stored at Port of PUS were utilized for some demands from Port of KWY and Port of USN as described earlier. However, the model has already solved that problem by desire to make empty container repositioning to those ports instead. The containers that available to be repositioned to Port of PUS then decrease which ultimately lead to an increase in inventory level. By this point, it can be said that as long as tank containers are efficiently repositioned to Port of KWY and Port of USN on-time in the right quantity as suggested by the model, inventory level at Port of PUS can be reduced.

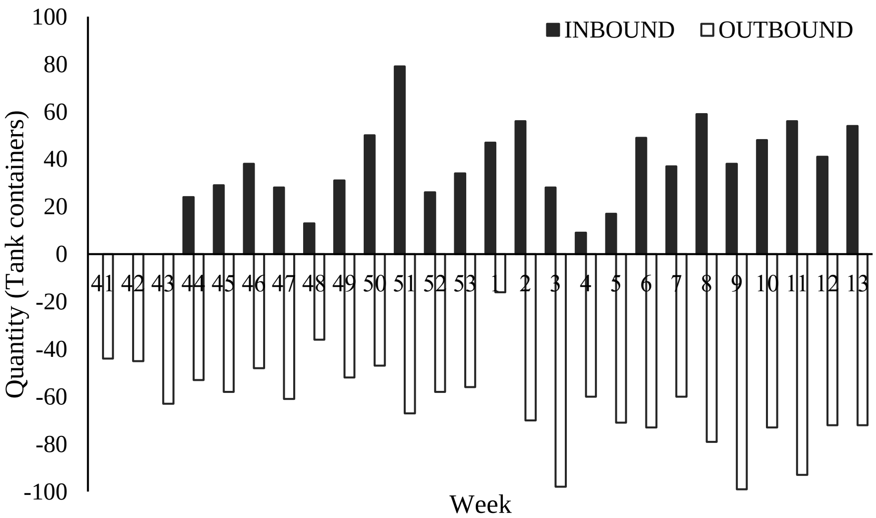

Figure 39 Inbound and outbound demanded tank containers at Port of PUS

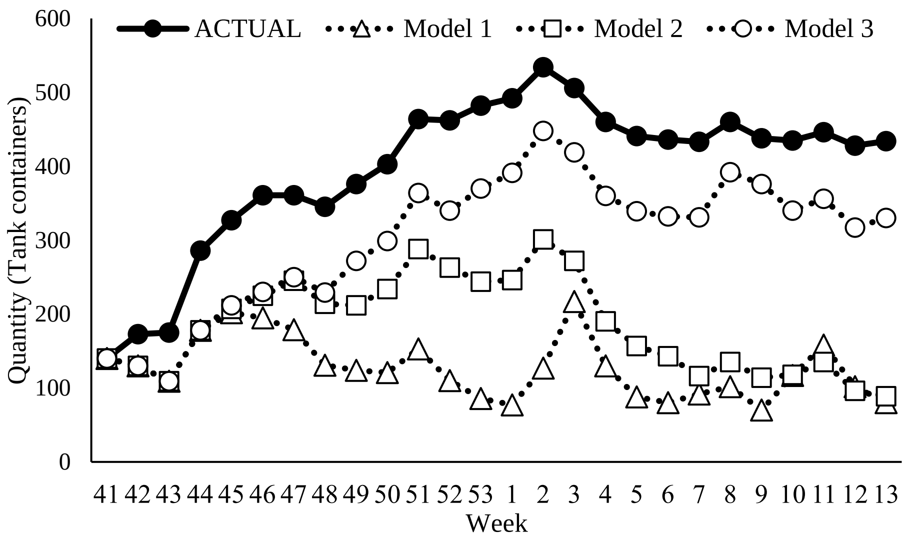

Figure 40 Inventory level at Port of PUS

4.2 Sensitivity analysis

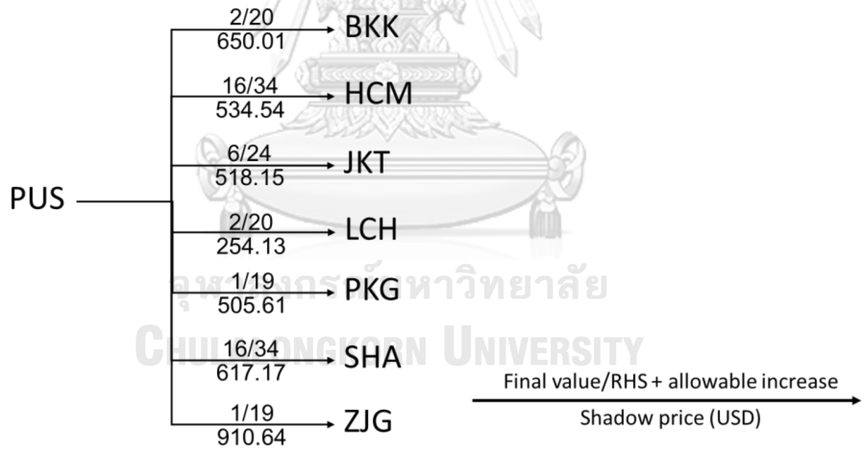

Figure 41 Shadow prices related to Port of PUS at week 43

Apart from computational results which provide optimal answer for each of decision variables, sensitivity analysis can be considered as a useful tool in operation planning of chemical tank container management. The obtained sensitivity table on constraints was analyzed and charted by each port of loading at a particular week. The origin-destination routes of which their final values are equal to the right-hand side were selected. By its definition, shadow price of this model is an increase in spot demand profit per an unit increase of spot demand parameter (Right-hand side of the constraints) in specific origin-destination route. In other words, if there is a non-zero shadow price shown in sensitivity table, it means that there are tank containers available to support additional spot demand in that route at a particular week. An allowable increase explains that how many of spot demand in that route can be increased without any changes of optimal operational decisions. An example of the said diagram is portrayed in figure 41. It shows that, at week 43, all 7 spot demand routes which originated from Port of PUS, i.e., PUS-BKK, PUS-HCM, PUS-JKT, PUS-LCH, PUS-PKG, PUS-SHA, and PUS-ZJG routes, are fully accommodated. From the comparison of their shadow prices, it can be described that PUS-ZJG is the most profitable route which amounted to 910.64 USD per tank container. The final value of spot demand accommodation of PUS-ZJG route is 1, while there are 18 allowable increases shown in this route. This means that the company can specifically promote sales volume in PUS-ZJG lane at the maximum number of 18 tank containers without any changes of operational decisions at optimal basis (empty container repositioning and demand accommodation at other routes) derived from model. This information from sensitivity analysis would help sales and marketing team to selectively choose the right trade lanes to maximize company profit. That is, it enables them to focus on high profitability routes. In addition, it also facilitates them to desire the right quantity of tank containers sales under optimal operational decision derived from the model.

Chapter 5
Conclusion

5.1 Conclusion

Tank container has played a vital role in chemical logistics and transportation owing to its various advantages over conventional packaging such as plastic drums and containerized bags. Like general container, tank container business also encounters with operational challenges from the imbalance of trade flows as well as uncertainty and volatility of customer demands. There are totally three areas to be considered in tank container operation, namely, container routing, empty container repositioning, and leasing decision. These factors are intertwined and relate to each other. So that, tank container management is considered as an important task for tank container operators. Having said that, Company A lacks that system for realistic decision support.

In this work, the author, thus, aim to develop an optimization model for chemical tank container management using linear programming methodology. The objective function of the model is to maximize net profit of the operations while determine decision variables: spot demand accommodation, empty tank container between international ports, empty tank container between domestic ports, and container spot leasing. There are five basic constraints occupied in the model. One is related to spot demand accommodation, whereas the others are the conversation of tank container flow and its movement according to assumed lead time. Some constraints may, in addition, be added to promote empty container repositioning from the ports that do not have outbound demands. This is to allow the model to behave alike the actual operation and avoid unnecessary inventory costs. On top of that, financial incentives may be added in objective function to guide the model decision regarding to inventory stock-up for future demands.

To illustrates behavior of each model according to applied constraints and objective function, three models are solved independently. The models are tested by using Company A's 6-month historical data between October 2020 to March 2021. The model is solved by a rolling horizon approach using OpenSolver as a software.

The results reveal that Model 3, of which adds additional repositioning constraints and utilizes financial incentives, provide the most alike actual operational decision as evidenced by tank container inventory level at import-dominant ports. It promotes empty container repositioning from the ports that do not have outbound demands which include Port of BKK, Port of HPH, Port of HCM, Port of HKG and all Japan ports. This can avoid unnecessary inventory holding costs at those ports. The model, in addition, unveils the difference between model result and actual operation of inventory level at the destination ports of empty container repositioning. On one hand, the model result in lower level of tank container inventory at Port of LCH than actual. Meanwhile, spot demands originated at that port are almost fully accommodated. This means that there was an excessive amount of tank containers that repositioned to Port of LCH. On the other hands, the model result in higher level of inventory at Port of KWY and Port of USN than actual. To be exact, the inventory level from model is expressed in positive rather than negative figures calculated from actual operation. This indicates that the model desire to have empty container repositioning to those ports compared with historical decision. By these outcomes from the model decision, Company A could save operating costs from unnecessary empty container repositioning. On top of that, the company could eliminate additional trucking charge that arrange to pick-up tank containers at different ports. In other words, using the developed Model 3 to determine operational decision allow the company to precisely plan empty container repositioning according to on-hand spot demands.

As for financial figures, Model 3 results in 3.39% lower profit from spot demand accommodation comparing with actual operation. There are three main reasons behind this. Firstly, empty container repositioning cost is greater than spot demand profit. Secondly, the model could not recognize the magnitude of future spot demand parameter in the next rolling horizon. Thirdly, the model does not allow tank containers to be picked-up at different ports. Empty container repositioning cost between international ports from the model is 12.46% greater than actual. This is due to the fostering of empty container repositioning by financial incentives. Even though the costs between international ports is risen, cost of empty container repositioning between domestic ports decrease by 42.38%. Ultimately, net profit from model results is 5.76% greater than an actual figure which is accounting for 1,281,498.86 USD.

In addition to computation results, sensitivity analysis provides two useful information, namely, shadow price and allowable increase in particular origin-destination route. By specifically consider information of each port of origin, shadow prices can signify the highest profit route. This helps sale and marketing teams to focus on the right trade lanes with high profitability. On top of that, allowable increase indicates the maximum of sales in a unit of tank container that can be enhanced in specific origin-destination route without any changes of optimal solution. This can also guide sales and marketing teams of the limitation of sales volume unless additional empty container repositioning decision is not desired.

To sum up, a developed optimization model provides operational plan at optimal decision regarding spot demand routing, empty container repositioning, and spot container leasing for efficient tank container management. By using the model, the company now has a supportive evidence in managing tank container flow across the network. This reduces operating cost from unnecessary empty container repositioning and long-distance trucking which ultimately turn into higher profit. In addition to operational plan obtained from computational result, information from sensitivity analysis adds more insight on an identification of each origin-destination route profitability as well as a limitation of potential increased volume under optimal decision. These highlight advantages of having the model over the use of spreadsheet and individual adjustment for tank container management merely.

5.2 Recommendation

Although financial incentives can guide the model behavior to build up inventory at export-dominant ports, it may overrate empty container repositioning activities as evidenced from an increase in the cost of empty repositioning between international ports. Thus, instead of financial incentives, the model should include forecasting data of spot demand in the constraints of model formulation. This could allow the model to actively anticipate the needs of containers according to the forecast then desire empty repositioning at the right quantity. As a matter of fact, Company A have not ever done the demand forecast before. Forecasting method and techniques should be additionally studied.

A computation experiment of this model has been done by limited sets of data due to its unavailability of tank container inventory record at the starting week of exactly required period. So that, the author unfortunately missed the chance to test the model with full-year range of operational information. Literally, it can be said that the wider range of data, the more opportunities to understand historical operational decision through the comparison between actual records and model results. Reason being, the model would be experienced with various changing trends of contract demands from different bid-winning awards as well as fluctuation of spot demands from volatility of markets. Hence, if necessary data of wider period are collectively stored, making use of them in the model experimentation would be an advantageous.

As for sensitivity analysis, besides the uses of shadow price from sensitivity report introduced in chapter 4, the obtained shadow price can be used to calculate reduced cost of new origin-destination routes using. By the definition of reduced cost, it potentially indicates how much objective function parameter (spot demand profit in this study) would have to be improved to makes objective function positive at the optimal solution. So that, the calculated reduced cost from shadow price indicates that which new pairs of origin-destination is profitable. On top of that, it can even detail the amount of profit that could be adjusted to make those routes profitable. These would shed light on the new market identification in new routes aside from the company current network.

An optimization model is a core of Decision Support System (DSS) used in logistics intermediaries. The DSS is generally constructed by 4 components, namely, database, model base, knowledge base, and dialog base (Min and Eom, 1994). The database core of DSS could help firms to store more diversity and numbers of relevant data which would amplify the scope and strengthen the model results. The dialog base focuses on user interface and user friendliness of the system. The model base plays a vital role in identifying and assessing alternative operational plans according to inputs data. Thus, this developed model could be further adopted in an architecture of DSS network design for global tank container management. In other words, this optimization model has already concisely paved the way for future practical implications in the development of Decision Support System.

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APPENDIX

Table 5 Inventory level from Model 1 result

Port	BKK	LCH	KEL	KHH	TXG	BLW	JKT	SUB	INC	KWY	PUS	USN	KUV	SHA	LYG	NKG	QDO	ZJG	NAN	HUA
Week																				
41	0	99	0	23	10	37	30	0	15	40	140	41	1	118	2	47	2	25	1	31
42	1	79	2	23	6	32	29	0	25	26	130	81	1	108	7	47	2	25	1	35
43	2	75	0	30	7	24	33	2	0	44	109	72	0	89	5	58	4	17	1	32
44	5	106	0	16	8	17	51	4	0	67	178	76	0	94	10	46	16	8	8	55
45	12	156	0	13	9	5	73	5	8	34	202	66	2	95	15	31	15	9	10	59
46	22	156	5	24	8	16	83	8	34	76	195	84	7	102	21	19	15	10	9	60
47	36	185	0	36	0	27	71	8	7	54	179	62	0	105	14	15	19	10	9	61
48	51	179	0	20	0	22	78	8	14	44	131	60	0	95	24	14	8	10	11	78
49	57	184	0	21	2	5	85	8	23	29	124	44	3	43	42	14	12	8	13	83
50	67	189	0	19	4	0	87	8	31	57	121	39	7	48	38	10	10	9	15	94
51	70	196	0	16	3	30	92	8	0	59	153	11	0	60	34	11	6	10	17	95
52	80	188	3	14	6	27	68	8	0	35	110	19	0	44	33	13	5	9	16	97
53	86	170	0	15	0	22	82	10	0	30	86	17	0	20	25	11	8	5	33	104
1	93	160	0	33	1	8	94	10	6	17	77	27	0	39	32	17	8	6	35	106
2	93	153	0	41	1	8	97	10	15	70	127	31	6	35	47	28	8	6	35	108
3	94	112	0	47	5	5	84	10	17	94	217	37	6	47	45	37	23	6	39	113
4	99	87	0	31	2	5	85	10	0	88	130	45	0	39	41	33	19	6	39	113
5	105	62	1	33	2	5	94	10	0	53	88	50	0	41	37	30	17	7	43	120
6	114	23	1	18	0	23	81	10	3	65	80	46	0	42	36	23	16	8	35	137
7	114	79	1	31	3	11	66	10	4	44	92	44	0	39	39	16	8	9	35	137
8	88	59	1	44	6	8	83	10	0	49	102	47	0	53	25	13	7	9	32	137
9	91	56	2	26	12	5	97	10	0	41	70	55	0	61	19	14	5	9	32	137
10	96	85	2	19	11	12	95	11	4	38	117	55	0	64	19	17	6	6	36	137
11	56	54	2	24	4	37	88	11	0	42	158	54	0	61	15	15	4	6	38	132
12	58	49	2	34	6	26	73	11	3	38	102	50	0	29	7	7	2	7	40	140
13	59	48	3	17	10	21	94	11	0	28	80	50	0	38	2	5	4	7	40	140

Table 6 Inventory level form Model 1 result (Con.)

Port	PGU	PKG	HCM	HPH	MOJ	NGO	TYO	UKB	YOK	IWK	SMZ	OSA	HKG	SIN
Week														
41	0	99	0	23	10	37	30	0	15	40	140	41	1	118
42	1	79	2	23	6	32	29	0	25	26	130	81	1	108
43	2	75	0	30	7	24	33	2	0	44	109	72	0	89
44	5	106	0	16	8	17	51	4	0	67	178	76	0	94
45	12	156	0	13	9	5	73	5	8	34	202	66	2	95
46	22	156	5	24	8	16	83	8	34	76	195	84	7	102
47	36	185	0	36	0	27	71	8	7	54	179	62	0	105
48	51	179	0	20	0	22	78	8	14	44	131	60	0	95
49	57	184	0	21	2	5	85	8	23	29	124	44	3	43
50	67	189	0	19	4	0	87	8	31	57	121	39	7	48
51	70	196	0	16	3	30	92	8	0	59	153	11	0	60
52	80	188	3	14	6	27	68	8	0	35	110	19	0	44
53	86	170	0	15	0	22	82	10	0	30	86	17	0	20
1	93	160	0	33	1	8	94	10	6	17	77	27	0	39
2	93	153	0	41	1	8	97	10	15	70	127	31	6	35
3	94	112	0	47	5	5	84	10	17	94	217	37	6	47
4	99	87	0	31	2	5	85	10	0	88	130	45	0	39
5	105	62	1	33	2	5	94	10	0	53	88	50	0	41
6	114	23	1	18	0	23	81	10	3	65	80	46	0	42
7	114	79	1	31	3	11	66	10	4	44	92	44	0	39
8	88	59	1	44	6	8	83	10	0	49	102	47	0	53
9	91	56	2	26	12	5	97	10	0	41	70	55	0	61
10	96	85	2	19	11	12	95	11	4	38	117	55	0	64
11	56	54	2	24	4	37	88	11	0	42	158	54	0	61
12	58	49	2	34	6	26	73	11	3	38	102	50	0	29
13	59	48	3	17	10	21	94	11	0	28	80	50	0	38

Table 7 Empty container repositioning between internation ports from Model 1 result

POL	HCM	HCM	HCM	HCM	HPH	MOJ	NGO	TYO	UKB	YOK	IWK	SMZ	OSA	HUA	HUA	JKT	INC	PGU	HKG	HKG
POD	KWY	PUS	USN	LCH	PUS	PUS	PUS	PUS	PUS	PUS	PUS	PUS	PUS	PUS	USN	LCH	LYG	SIN	KWY	PUS
Week																				
41	29	0	14	0	0	0	0	0	0	0	0	0	0	0	31	0	0	2	0	0
42	0	0	39	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
43	12	0	3	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0
44	22	2	7	0	3	0	0	1	0	1	0	0	0	0	23	0	0	0	0	0
45	33	0	0	0	1	2	0	2	9	11	0	0	0	0	4	0	0	0	0	0
46	2	0	28	0	3	6	0	0	16	8	3	0	0	1	0	0	0	0	0	0
47	32	0	0	0	12	4	0	0	0	0	1	0	0	1	0	0	0	0	0	0
48	2	26	0	0	2	1	0	0	0	0	0	0	0	17	0	0	0	0	0	0
49	23	0	0	0	3	2	0	3	8	7	1	0	0	5	0	0	0	6	0	0
50	60	0	0	0	17	1	0	1	2	0	1	0	0	11	0	0	0	0	0	0
51	11	7	0	0	5	0	0	2	11	0	0	0	0	1	0	0	0	0	0	0
52	0	22	0	0	0	2	0	1	1	1	0	0	0	2	0	0	0	0	0	0
53	0	12	0	0	2	3	0	1	0	5	0	0	0	7	0	0	0	0	0	0
1	33	0	0	0	3	5	2	1	2	2	0	0	0	2	0	0	0	4	0	0
2	52	0	0	0	2	2	0	0	9	0	0	0	0	2	0	0	0	0	0	0
3	15	9	0	0	1	4	0	0	2	0	0	0	0	5	0	0	0	0	0	0
4	0	5	0	0	3	0	3	0	0	4	0	0	0	0	0	0	0	0	0	0
5	13	0	0	0	3	3	0	2	0	0	0	0	0	7	0	0	0	2	0	0
6	19	0	0	0	4	2	0	1	0	2	0	0	0	17	0	0	0	0	0	0
7	33	12	0	0	2	6	0	4	7	1	2	0	0	0	0	0	0	0	0	0
8	0	23	0	0	6	1	0	0	0	8	0	10	0	0	0	0	0	0	0	0
9	21	0	0	0	0	4	0	7	2	1	1	0	0	0	0	0	0	0	0	0
10	24	0	0	0	4	2	0	0	7	8	2	10	0	0	0	0	0	0	0	0
11	7	0	0	0	0	1	0	3	4	4	0	0	5	0	0	0	0	0	0	0
12	11	2	0	0	6	4	2	0	3	0	0	0	0	12	0	0	0	0	0	0
13	0	30	0	0	2	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0

Table 8 Empty container repositioning between domestic ports from Model 1 result

POL	BKK	KEL	KEL	KHH	TXG	SHA	LYG	QDO	ZJG	NAN	JKT	SUB	INC	KUV	PGU
POD	LCH	KHH	TXG	TXG	KEL	LYG	QDO	LYG	LYG	HUA	BLW	JKT	KWY	KWY	PKG
Week															
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	2	7	0	0	0	1	0	0	20	0	0
43	0	3	0	0	0	0	0	1	0	7	0	0	0	0	0
44	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	7	8	0	0	8	0	0	0	0	0	16	0	0	0	0
47	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	10	1	0	0	0	0	0	0	0	0	30	0	8	0	0
51	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	10	0	0	1	0	0	0	0	0	0	0	0	0	0	0
53	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	12	0	0	0	29
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	9	0	0	0	0	0	0	0	0	0	23	0	5	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	5	0	0	2	0	0	2	0	0	5	28	0	15	0	13
11	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	13	0	0	0	0	0	0	0	0	0	21	0	0	0	0

Table 9 Sensitivity analysis report on constraints of Port of PUS at week 43

POL	POD	Final Value	Shadow Price	RHS Value	Allowable Increase	Allowable Decrease
PUS	BKK	2	650.01	2	18	2
PUS	HCM	16	534.54	16	18	16
PUS	HKG	0	830.00	0	18	0
PUS	HPH	0	0	0	1E+100	0
PUS	HUA	0	0	0	1E+100	0
PUS	JKT	6	518.50	6	18	6
PUS	KEL	0	0	0	1E+100	0
PUS	KHH	0	0	0	1E+100	0
PUS	LCH	2	254.13	2	18	2
PUS	MOJ	0	0	0	1E+100	0
PUS	NAN	0	0	0	1E+100	0
PUS	NKG	0	0	0	1E+100	0
PUS	PGU	0	355.74	0	18	0
PUS	PKG	1	505.61	1	18	1
PUS	QDO	0	437.61	0	18	0
PUS	SHA	16	617.67	16	18	16
PUS	SIN	0	448.40	0	18	0
PUS	SUB	0	0	0	1E+100	0
PUS	TXG	0	0	0	1E+100	0
PUS	TYO	0	560.00	0	18	0
PUS	SMZ	0	0	0	1E+100	0
PUS	OSA	0	0	0	1E+100	0
PUS	ZJG	1	910.64	1	18	1

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