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Port cooperation for competition in international maritime network

（国際海運ネットワークにおける競争のための港湾協力）

A Dissertation
Submitted to the Department of Transdisciplinary Science and Engineering
in Partial Fulfilment of the Requirements of the Degree of
Doctor of Engineering

Hoshi Tagawa
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Department of Transdisciplinary Science and Engineering
School of Environment and Society
Tokyo Institute of Technology

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ABSTRACT

The number of container ports that cooperate to improve port productivity or profitability has been increasing. Various types of port cooperation have different business scopes, such as terminal management and port access. For these cooperation types, the motivations are divided into two types based on the market in cooperation: regional welfare or competition. The main objective of this study is to reveal the effectiveness of port cooperation in competition with a strong competitor. This study analyzes the cooperation for competition from three perspectives; evaluation of current cooperation in Kobe and Osaka ports in Japan, port choice by the shipper on the demand side, and network design by the shipping line on the supply side.

First, this study evaluates the impact of port cooperation on a port hierarchy based on network analysis. Specifically, this study analyzes the cooperation between Kobe and Osaka ports (Hanshin port) in the Japanese cargo network compared to a strong competitor, the Busan port (Korea). The network is built based on Japanese cargo in 2008 and 2018 because the cooperative strategy for Kobe and Osaka ports was designed in 2010. As for the cargo in 2018, this study prepares two networks: without and with a synergistic effect called 2018 (Base) and 2018 (Coop), respectively. The comparison between 2008 and 2018 (Base) indicates the impact of current port cooperation on the network. The comparison between 2008 and 2018 (Base) indicates the expected impact of port cooperation in the network. This study finds that the current cooperative strategy did not realize the higher connectivity of Hanshin port than Busan port. The comparison between 2018 (Base) and 2018 (Coop) indicates whether building cooperative relationships contribute to a higher position in the port hierarchy and affects the network configuration, such as creating a higher interconnection of ports as a community structure.

Secondly, this study simulates the effective cooperative strategy of ports for competition with two simulations considering the relationship between port and shipper as the demand side. This study analyzes the three ports competing or cooperating in a linear city where shippers are uniformly distributed in the first simulation. The first simulation derives and compares the cooperative effort as cooperation level, which indicates the willingness to participate in port cooperation as optimum cooperation to fit each motivation that includes cooperation for regional welfare and competition. The focus market differentiates the motivations in the simulation. The optimum cooperation levels for regional welfare and competition are different because of the difference in the cooperation effects in each motivation. Additionally, this study develops the bi-level optimization model with three equilibriums to reveal the more detailed cooperative strategies in the second simulation. This study applies the model to a case study of the competition between Hanshin and Busan ports. Optimum cooperation type changes depending on the focusing market. Specifically, cooperation to reduce the shipping time is effective for Hanshin port to compete with Busan port in North American cargo.

Third, this study simulates the effective cooperative strategy of the port for competition, considering the relationship between the port and shipping line on the supply side. This study solves the liner shipping network designing problem, defined as the task of designing a set of weekly services, assigning vessels to the services, and flowing the demand through the resulting network. The answer to the problem indicates the deployment of shipping services to two hundred-one ports worldwide. This study analyzes the impact of five scenarios about cooperation between Kobe and Osaka ports as Hanshin port. This study obtains the following two findings. First, port cooperation is an effective strategy for competition in terms of increasing centrality in the shipping network. Second, port cooperation influences ports other than cooperative ports, and the impacts are different depending on the ports and scenarios. Specifically, although Hanshin port can obtain enough competitiveness to compete with Busan port as a strong competitor, Hong Kong port, as another strong competitor, increase the centrality in the network.

The findings in this dissertation conclude that cooperation contributes to the increase of competitiveness of cooperative ports. However, the competitiveness is weaker than the strong competitor. Cooperation is a trigger to increase competitiveness. An additional strategy to continuously increase the competitiveness for stronger competitiveness than a competitor, which is not necessarily port cooperation, is needed.

Some findings of this dissertation might have policy implications. The results related to network analysis of Kobe and Osaka ports in the Japanese cargo network indicate that low synergistic cooperation cannot realize higher competitiveness than a strong competitor. The results related to the relationship between ports and shippers indicate the importance of considering the port situation and focusing market to realize the optimum cooperative strategy for competition. The results related to the relationship between ports and shipping line indicate that although cooperation can obtain competitiveness enough to compete with a strong competitor, another strong competitor occur with the port cooperation. This dissertation has significant contributions through policy suggestions for cooperation for competition.

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CHAPTER 1: Introduction

1.1 Background

Container ports serve as a facilitator for the efficient flow of container cargo. A high-competitiveness port, which can realize low-cost and high-performance transport, attracts more shipping services and collects more cargo (Ducruet and Notteboom, 2012a). The decision by shipping services to stop calling at a port results in reduced connectivity, choice of service providers, and container throughput. The increase in shipping services and cargo can increase the benefits beyond the container port community and transport users to society (Notteboom and Yap, 2012). Additionally, the difference in port competitiveness causes a port hierarchy due to the uneven distribution of shipping services and cargo. Ports in a high position in the port hierarchy contribute to the economic development of port regions as the central point of container cargo trade. Thus, the port competition for a higher port hierarchy position has intensified for economic growth.

Port cooperation, defined as the relationship between two or more ports pursuing a common goal (Inoue, 2018), is considered an effective strategy for improving productivity and profitability (Takebayashi and Hanaoka, 2021). The port industry has recently experienced a multiplication of port cooperation (Notteboom et al. 2018). For example, in the cooperation between the Ningbo and Zhoushan ports in China, port planning and investments, as well as the management of the port coastline, are integrally implemented (Notteboom and Yang, 2017). Rotterdam and Amsterdam ports in the Netherlands have invested in a company that offers paths for trains between Dutch seaports and the European hinterland (Donselaar and Kolkman, 2010). Various types of port cooperation have different business scopes, such as terminal management and hinterland access (Inoue 2018). Optimum port cooperation depends on the situation surrounding the ports, such as port congestion (Takebayashi and Hanaoka, 2021) and the similarity of ports (Cui and Notteboom, 2018).

These cooperative strategies can be divided into two categories based on the focus of cooperation: regional welfare and competition. Figure 1.1 shows the location of the port with the two cooperation focuses. Regional welfare cooperation aims to increase the welfare of common regions with cooperative ports by solving problems such as hinterland congestion and duplication in port facilities. For example, joint port operations and management are planned in Dalian and Yingkou ports to avoid excessive competition (Wu and Yang, 2018). In regional welfare, port cooperation aims to develop an efficient port service and build a win-win relationship as an alternative to competition for regional welfare. Cooperation for competition aims to solve problems such as the loss of combined market share in neighboring ports due to the emergence of a strong competitor. For example, the Seattle and Tacoma ports in north-western America established a joint organization to manage their marine cargo terminals because they recognized the common threat of losing more market share to neighboring Canadian ports, such as the Vancouver port (Inoue, 2018). Kobe and Osaka ports in Japan also established a joint management company to manage both ports for competition with Busan in the transshipment of cargo originating in Japan (Kawasaki et al., 2020). Port cooperation aims to realize a higher market share than the competitor through higher competitiveness from synergistic effects between ports, such as economies of scale. The significant difference between cooperation for regional welfare and competition is the focus of cooperation. Specifically, regional welfare cooperation focuses on markets shared with ports that aim for cooperation. Competition cooperation focuses on the market share with a third competitor. Table 1.1 summarizes the above motivation for cooperation.

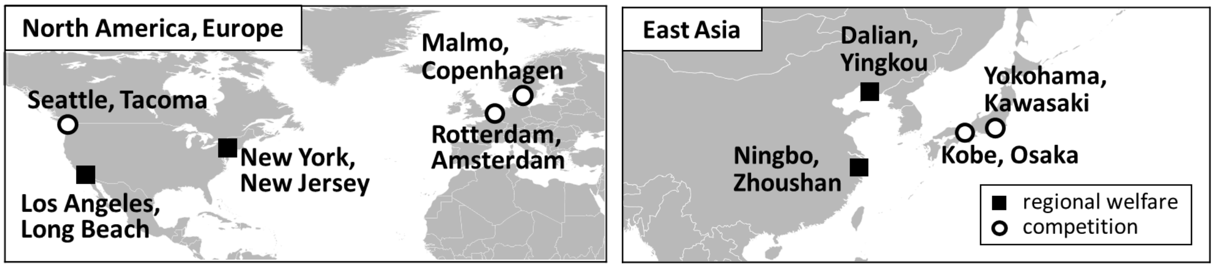


Figure 1.1 The location of cooperative ports

Table 1.1 Motivation and expected effect of port cooperation

Motivation	Regional welfare	To increase the welfare in the market shared with cooperative ports
	Competition	To increase the cargo in the market shared with competitive ports
Expected effect	Efficiency improvement	Improvement of ports by preventing overcapacity, the economy of scale, partitioning risks, knowledge exchange, and so on.

Source: Donselaar and Kolkman (2010)

Although many studies have examined port cooperation, most have focused on regional welfare cooperation. For example, Munim and Haralambides (2018) found that cooperation between the Kolkata ports in India and the Mongla and Chittagong ports in Bangladesh benefited overlapping port users. Wang et al. (2012) explained that port cooperation in maximizing joint profit resulted in a higher port charge and that their profits increased compared with those in competition. These studies showed that port cooperation achieved win-win relationships with increased regional welfare. The former study showed how cooperation reduced the transportation costs of shippers, and the latter studied the increase in profits of the two ports. However, cooperation for competition, one of the major motivations for cooperation, has not been fully analyzed. There needs to be more research regarding whether cooperation is practical for competition. Additionally, if we apply the findings of previous studies in cooperation for regional welfare, the reduced transportation costs of shippers can contribute to cooperation for competition. However, higher prices for an increase in the profit of each port do not fit the motivation for cooperation for competition because ports should set lower prices in competitive situations (Ishii et al., 2013). This application reveals the research question of whether optimum cooperation to fit the motivation is different.

1.2 Research Objectives

This dissertation analyzes the cooperation for competition with a strong competitor. Although container throughput has been used as a measure of port competition, it cannot always precisely reflect the importance of ports due to their different functions. For example, the Busan port in Korea is an essential linkage for Japanese ports to connect with other Asian ports due to the betweenness (Kawasaki et al. 2019). Thus, the impact of indicators other than container throughput needs to be evaluated for port cooperation. Additionally, Table 1.2 shows the difference in port competitiveness from the perspective of the shipper or forwarder as demand and the shipping line as the supplier in maritime transport (Yuen et al. 2012). Shippers or forwarders are the people or companies that want to transport the cargo and decide how to transport it. We refer to both shipper and forwarder as the shipper in this study. They give importance to port location and hinterland connectivity. On the other hand, shipping lines, which are a company that provides shipping services to transport cargo, give priority to cost at the port. The different weights can result in different evaluations of the cooperation. The port cooperation needs to be evaluated from both the shipper and shipping line perspectives to reflect the different weights. Previous studies, such as Trujillo et al. (2018) and Krogsgaard et al. (2018), have developed mathematical models to analyze the relationships between port and shipper and between port and shipping line. Models that include the perspectives of shippers or shipping lines realize quantitative discussion about cooperation for competition.

Table 1.2 Importance weightings and consistency ratios by the analytic hierarchy process

	Shipper (demand)	Forwarder (demand)	Shipping line (supply)
Port location	21.34 %	22.44 %	10.50%
Costs at port	15.48 %	12.97 %	26.44%
Port facility	7.45 %	3.89 %	10.45 %
Shipping services	11.52 %	17.57 %	7.74 %
Terminal operator	5.58 %	4.00 %	11.92 %
Port information system	7.47 %	5.42 %	7.24 %
Hinterland connections	15.90 %	18.35 %	12.80 %
Customs and government regulation	15.26 %	15.35 %	12.88 %
Consistency ratio	0.04	0.05	0.07

Source: Yuen et al. (2012), modified by author

Therefore, this dissertation first analyzes the impact of port cooperation on a port hierarchy based on network analysis, which can evaluate the regional and global importance of a port or route (Montes et al. 2012, Ducruet et al. 2010). Second, this dissertation focuses on port competition from the relationship between port and shipper. Finally, this dissertation focuses on port competition from the perspective of the relationship between port and shipping line. The detailed objectives are as follows

Primary objective: To reveal the effectiveness of the port cooperation for competition

(1) This dissertation analyzes the primary objective in the international maritime network. We evaluate the hierarchy of the Hanshin port (Kobe and Osaka) compared to a strong competitor (the Busan port) in the Japanese cargo network. (Chapter 3)

(2) This dissertation analyzes the primary objective from the perspective of port and shipper as the demand in maritime transport. We implement the two types of simulation to reveal the optimum cooperation level, which is the willingness to participate in port cooperation, and detailed cooperation types, which is the business scope as a cooperative strategy. (Chapter 4)

(3) This dissertation analyzes the primary objective from the perspective of port and shipping lines as the supply in maritime transport. We solve the liner shipping network design problem to explore the impact of port cooperation between Kobe and Osaka ports on network design by the shipping line. (Chapter 5)

1.3 Outline

Chapter 1 introduces this dissertation's background, research objectives, scope, and limitations.

Chapter 2 reviews related previous studies with the three perspectives; port cooperation, port competitiveness, and network design.

Chapter 3 analyzes cooperation between Kobe and Osaka ports (aggregated Hanshin port) in Japan. The cooperation of the Hanshin port was designed in the International Container Strategic Port (ICSP) policy in 2010 to maintain and expand the number of port calls in trunk lines to Japan. The Kobe and Osaka ports were managed by a joint management company called the Kobe-Osaka International Port Corporation and intended to increase the competitiveness of the Hanshin port through integrated terminal management (MLIT, 2016). The cooperation in the ICSP policy also aimed to increase container volume at the Hanshin port, which competes with East Asian hub ports such as the Busan port in South Korea for transshipped container cargo originating from or destined for Japan (MLIT, 2016). Therefore, we evaluate the hierarchy of the Hanshin port (Kobe and Osaka) compared to a strong competitor (the Busan port) in the Japanese cargo network by discussing the expansion of the trunk line in the Hanshin port.

Chapter 4 implements two types of simulation to explore the optimum cooperation level and cooperation types with considering the relationships between port and shipper. The first simulation analyzes the three ports competing or cooperating in a linear city where shippers are uniformly distributed. The game-theoretical model is developed in the first simulation. We analyze four scenarios in which we changed the transport cost, port competitiveness, public level, and cost reduction by cooperation to obtain optimum cooperation level in various realistic port situations. The second simulation implements a case study of the cooperation between Kobe and Osaka in the competition with Busan. The bi-level optimization model with three equilibriums is developed in the second simulation. We analyze six scenarios about detailed cooperation types.

Chapter 5 solves the liner shipping network designing problem to analyze the impact of port cooperation on the shipping line. The liner shipping network design problem is defined as the task of developing a set of weekly services, assigning vessels to the services, and flowing the demand through the resulting network (Christiansen et al. 2020). The answer to the problem indicates the deployment of shipping services to ports around the world. We analyze the five scenarios, which include depth, port charge, cargo increase, cargo concentration, and all scenarios to show the different impacts on the shipping network by cooperative scenarios.

Chapter 6 summarizes this dissertation's results and findings and proposes future scopes.

Table 1.3 summarizes the focus of chapters 3-5. Chapters 3 and 5 focus on the cooperation between Kobe and Osaka ports considering the competition with Busan port as the strong competitor. The perspectives of evaluation are different in the chapters. Chapter 3 analyzes the actual Japanese cargo flow. Chapter 5 focuses on the relationship between ports and shipping lines. Chapter 4.2 explores the hypothetical ports in a linear city. Two ports are cooperating while competing with the third port. Chapter 4.3 focuses on cooperation between Kobe and Osaka ports and competition between Kobe and Busan ports in the relationship between ports and shippers. Figure 1.2 illustrates the relationships of ports in each chapter.

Table 1.3 Focus of each chapter

	Focus	Cooperative ports	Competitor
Chapter 3	Actual Japanese cargo flow	Kobe and Osaka	Busan
Chapter 4	Simulation of shipper’s port choice (ports and shipper)	Ch. 4.2: Hypothetical two ports	A port
		Ch. 4.3: Kobe and Osaka	Busan
Chapter 5	Simulation of linear network design (ports and shipping line)	Kobe and Osaka	Busan

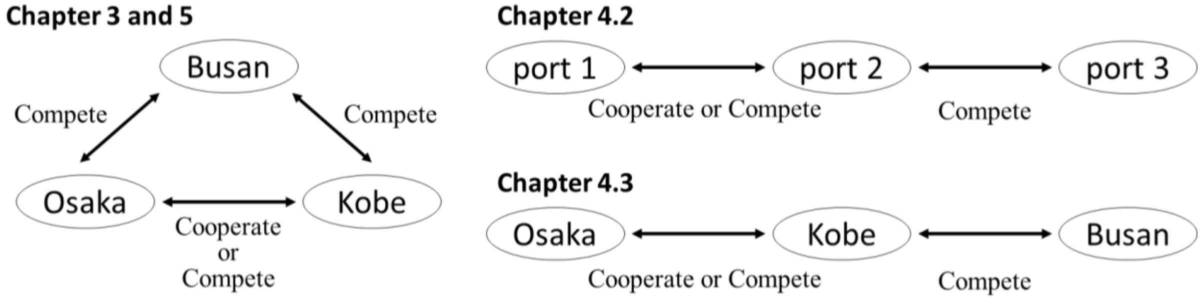


Figure 1.2 Relationships of ports in each chapter

1.4 Scope and limitations

This dissertation focuses on port cooperation and assumes that port cooperation realizes the expected effect. We do not consider the difficulty of building port cooperation, such as compliance with the regularity of competition and governance involving decision-making at the highest levels in the port cooperation, as discussed by Yoshitani (2018) and Knatz (2018). The case where the cooperation does not realize the expected effect, like the cooperation between Kobe and Osaka ports as discussed in Kawasaki et al. (2020) and Inoue (2018), is not supposed.

Although the analyzed ports in Chapter 3 are all over the world that includes local ports, the cooperation in Chapter 3 is simplified as an aggregation of nodes about Kobe and Osaka. Although the cooperation in Chapter 5 is considered with various scenarios, the analyzed ports in Chapter 5 are 201 ports, not including ports all over the world, especially in local ports.

Chapter 4 simplifies the shipping line's decision to analyze the relationship between the port and shipper in the simulation. Chapter 5 simplifies the decision of the shipper to explore the relationship between the port and shipping line in the simulation. The relationships among the port, shipper, and shipping line are not analyzed.

Other limitations in each chapter are as follows:
Chapter 3 has one notable limitation: The study in Chapter 3 analyzes the Japanese cargo network in 2008 and 2018. The network change from 2008 to 2018 was affected by several factors other than port cooperation between Kobe and Osaka ports. Other changes, such as the bankruptcy of Hanjin Shipping, influenced the Japanese cargo network.

Chapter 4 has two notable limitations: First, the study in Chapter 4 analyzes the cooperation or competition between three ports. The port competes with several nearby ports, not necessarily three, and the cooperative strategy might be changed. Second, the simulations in Chapter 4 simplify the distribution of shippers, such as a linear city or a limited number of shippers. The different densities of shippers might influence the optimum cooperative strategy.

Chapter 5 has one notable limitation: The study in Chapter 5 analyzes the shipping network design by one shipping line. Multiple shipping lines design their shipping services while competing with each other in actual maritime transport, and competition might influence the network design and freight rate.

1.5 Contributions

This dissertation fulfills the research gaps regarding whether cooperation is practical for competition by the three perspectives from Chapters 3 to 5. The detailed contributions of this dissertation are as follows:

Chapter 3 analyzes the cooperation between Kobe and Osaka ports for the competition with Busan port from the perspective of network scale instead of container throughput, a traditional measure to evaluate the port competitiveness. The study contributes to previous studies by providing new findings such that port cooperation affected the network configurations and contributed to a higher position in the port hierarchy. The results can assist policymakers engaged in port management in attaining higher positions in the port hierarchy through port cooperation.

Chapter 4 explores the optimum cooperation level and types considering the relationships between port and shipper. The study contributes to previous studies by providing new findings such that optimum cooperation levels and types change depending on the port situation and the focusing market. The results can assist policymakers engaged in port management by serving as methodological references for developing cooperative port strategies for the competition from the shippers' perspective.

Chapter 5 evaluates the impact on the liner shipping network designing of the shipping line by the port cooperation. The study contributes to previous studies by providing new findings, such as the impact of port cooperation on shipping network design. The results can assist policymakers engaged in port management by suggesting the estimation of the shipping network for the realization of higher port competitiveness than the strong competitor by the port cooperation with the perspective of the shipping line.

CHAPTER 2: Literature review

This study focuses on cooperation for competition. We categorized relevant previous studies into three; port cooperation, port competition, and network design.

2.1 Port cooperation

Port cooperation has been investigated in previous studies. Several studies analyze the port cooperation for regional welfare to realize the increased welfare of shared regions. Trujillo et al. (2018) developed the theoretical model in a linear city with two ports and proposed that a collusive agreement regarding the optimal total capacity in cooperative ports resulted in higher profits for both ports by exploiting economies of scale. Donselaar and Kolkman (2010) mentioned that cooperation could solve the problem of less necessary port-related investment through competition and could reduce costs through efficiency improvements, such as preventing overcapacity and economies of scale. Hintjens et al. (2020) discussed that hinterland bundling through cooperation reduced the cost as the economy of scale and resulted in an increase in consumer surplus. Wu and Yang (2018) analyzed the cooperation between Dalian and Yingkou ports to avoid excessive competition. Munim and Haralambides (2018) a mixed integer linear programming optimization model and indicated that shippers in two landlocked countries in South Asia, Nepal and Bhutan, benefited from the cooperation among the Kolkata port in India and the Mongla and Chittagong ports in Bangladesh. Yang et al. (2019) analyzed the optimal scale of cooperative ports to minimize the costs associated with port industry transformation and upgrading.

Several studies have shown the conditions required to realize port cooperation with win-win relationships instead of competition. Takebayashi and Hanaoka (2021) developed the bi-level optimization model between carrier and ports and revealed that cooperation in a congested port was successful when each port authority considered the benefits to its local customers in terms of shipping costs. Wang et al. (2012) concluded that port cooperation was established only when there was a balance between the price-rising effect, which involves increasing port prices, and the output-switching effect, which involves switching some of the throughputs from high to low-cost ports. Kawasaki et al. (2020) demonstrate that ports should maintain competition instead of cooperating when cargo demand is low because the effect of economies of scale is relatively low in smaller cargo demand. Additionally, several studies have shown the difficulty of realizing port cooperation. Knatz (2018) mentioned that the Los Angeles and Long Beach ports, which are in proximity, failed to build cooperative strategies because of the lack of clear benefits for each port and city. Yoshitani (2018) and De Langen and Nijdam (2009) explained the practical challenges to realizing the cooperation between Seattle and Tacoma ports and Copenhagen and Malmo ports, respectively. Although Zhou (2015) developed the model analyzing the cooperation of two ports with a third competitor as cooperation for competition, the influential conditions investigated in previous studies were not analyzed.

Several studies have analyzed the importance of the correct balance of competition and cooperation between two cooperative ports, which Song (2003) explained as coopetition. Dong et al. (2018)

concluded that cooperation could improve resource utilization with economies of scale. However, once the degree of port cooperation exceeds the threshold, container throughput experiences a slowdown in growth or even becomes negative owing to diseconomies of scale. Lee and Song (2017) mentioned that although the concept of port coopetition has existed for a decade, empirical or modeling research still needs to be fully implemented. Several studies have not focused on port coopetition but on the coopetition of other players in maritime transport, such as shipping lines and terminal operators. For example, Lin et al. (2017) derived the optimum coopetition level for shipping lines to maximize their profits. The optimum levels change depending on the path cost and market size. Kavirathna et al. (2019) analyzed the coopetition of terminal operators and showed that operator incentives change depending on the combination of terminal ownership.

In summary, previous studies related to port cooperation indicate that port cooperation contributes to regional welfare with the improvement of productivity of both ports. The port cooperation succeeds under limited conditions, and optimum port cooperation changes depending on the situation surrounding the ports—especially the correct balance of competition and cooperation. Coopetition is essential to realize effective port cooperation.

2.2 Port competition

Port competition has been investigated in previous studies. Several studies analyzed the port competition to obtain more cargo than competitive ports. Zondag et al. (2010) analyzed the competition to acquire cargo among Antwerp, Rotterdam, Bremen, and Hamburg ports with the cost of logistic chains. Wan et al. (2016) stated the importance of considering the two types of hinterland markets, which include the captive local market and the contestable inland market. The inclusion of captive markets substantially changes port price strategy because ports need to balance their monopoly power in the captive market with the competition in the contestable inland market. Kawasaki et al. (2021) showed the competition between Manila and Batangas ports in a market with two types of cargo density suburb and city areas. Additionally, several studies have revealed the influential factor on port competitiveness. Cui and Notteboom (2018) and Kavirthna et al. (2019) indicated the difference in the competition with the publicness of port authority. Ng and Kee (2008) stated that shipping lines deployed larger-sized vessels in ports with berths deep enough for larger-sized vessels to call to achieve lower unit costs with larger-sized vessels, which indicated the depth of berth in the port was an influential factor to call vessels. Hintjens (2018) pointed out the importance of better hinterland connections to attract more cargo.

Several studies have implemented network analysis to reveal the port hierarchy in complex maritime networks. Ducruet and Notteboom (2012a) analyzed the global liner shipping network in 1996 and 2006, a rapid change in port hierarchy. Although several ports in East Asia and the Mediterranean obtained a higher position in the port hierarchy from 1996 to 2006, growth did not alter the established positions of hub ports such as Singapore and Algeciras. Hu et al. (2020) and Tsiotas and Polyzos (2015) focused on networks in East Asia and Greece, respectively, to show regional-level interactions. Additionally, several studies have revealed the importance of a specific node in the network as a vulnerability. Viljoen and Joubert (2016) simulated network disruption and analyzed the vulnerability of maritime networks based on the dependency of specific nodes. Ducruet (2016) and Wu et al. (2019) pointed out the importance of the two major interoceanic canals, the Suez and Panama canals, in the maritime network by evaluating a network in which the canals were interrupted. Ports with high centrality in the network have high competitiveness to cargo or ports of call by vessels.

In summary, previous studies related to port competition indicate that cargo throughput has been used to measure the change in port competitiveness, and port competitiveness is affected by several factors. Additionally, network analysis can be used to evaluate the change in port competitiveness with the hierarchy in the maritime network.

2.3 Network design

Network design has been investigated in previous studies. Several studies revealed the difference in network configurations. Kaluza et al. (2010) and Mou et al. (2018) revealed the difference in network configurations of several cargo ship movements, such as container, bulk, and oil. Calatayud et al. (2017) and Kawasaki et al. (2019) analyzed the differences in shipping networks among shipping companies. Additionally, several studies analyzed the change in network configuration to international events. Fang et al. (2018) derived maritime network dynamics to determine the potential effects of international events, such as military conflicts. Montes et al. (2012) and Gonzalez-Laxe et al. (2012) evaluated the container cargo network from 2008 to 2010 to reveal the impact of the financial crisis of 2007–2008. Dirzka and Acciaro (2022) and Guerrero et al. (2022) analyzed the change in network configuration caused by COVID-19 and reported the different effects on the port hierarchy by the mitigation measures.

Several studies analyzed the network design of shipping lines. Chen et al. (2020) and Sun and Zeng (2016) developed a mathematical model to derive the hub port location in the shipping network design. Wang and Meng (2012) and Aydin et al. (2017) analyzed optimum sailing speed to save fuel costs in shipping service. Zheng et al. (2015) and Gelareh et al. (2013) studied the problem of designing a hub-and-spoke network with considering fleet management. Wilmsmeier and Notteboom (2011) showed that liner shipping networks seem to follow a specific evolutionary pattern. Christiansen et al. (2020) and Ksciuk et al. (2022) summarized the studies related to shipping networks and showed the importance of analysis of the impact on shipping networks by introducing new technology, such as autonomous vessels.

Several studies analyzed the vertical cooperation between ports and shipping lines. Jiang et al. (2021) showed that although the vertical investment of shipping companies in ports will increase their profits, the interest of other competitors and social welfare could be harmed. Wang and Meng (2019) derived the optimal price between port operators and shipping lines under port congestion. Zhu et al. (2019) discovered that vertical cooperation increases the participating carrier’s output at the expense of a non-integrating rival shipping firm. Song et al. (2018) demonstrated that port investment would raise the prices charged to shippers, and the Pareto gains of the supply chain may be realized at the cost of extracting more surplus from shippers. Additionally, several studies analyzed the cooperation between shipping lines as a shipping alliance. Notteboom et al. (2017) discussed the reasons for forming a transportation alliance and the relationship between port choice and the organization of a shipping alliance. Song and Wang (2022) considered slot allocation and exchange for a shipping alliance. Ship capacity and demand level affect the alliance's optimal slot allocation and exchange strategy. Caschili et al. (2014) analyzed how shipping companies integrated and coordinated their activities and investigated inter-carrier relationships' topology and hierarchical structure by constructing the Cooperative Container Network.

In summary, previous studies related to network design indicates that the shipping network change depending on the shipping line strategy or some events. Additionally, although the cooperation of shipping lines has been discussed in cooperation between shipping lines or between shipping line and port, the impact cooperation of port have not been analyzed.

2.4 Summary

Based on the above reviews, previous studies have not fully analyzed cooperation for competition compared to cooperation for regional welfare. Additionally, studies about port cooperation indicated the optimum port cooperation change depending on the situation surrounding the ports. Studies about port competitiveness revealed that network analysis could be used to evaluate the change in port competitiveness with the hierarchy in the maritime network. Studies about network design showed the network design change by several events. The review of previous studies revealed the following three significant research gaps;

Gap 1: Conditions to success the cooperation for competition have not been revealed
Gap 2: Changes in port competitiveness by port cooperation have not been analyzed in the network
Gap 3: Network designing of the shipping line as a supplier has not been analyzed in port cooperation

Each chapter fulfills the three research gaps. Specifically, Chapter 3 mainly focuses on Gap 2 and also concentrates on Gap 3 by evaluating cooperation as Hanshin port in the maritime network. Chapter 4 focus on Gap 1 with the derivation of optimum port cooperation in different cooperative motivation. Chapter 5 mainly focus on Gap 3 and also concentrate on Gap 2 with the estimation of network designing change by shipping line due to the port cooperation. Table 2.1 shows the position of this dissertation in previous studies.

Table 2.1 Research position in the previous studies

	Cooperation for regional welfare	Cooperation for competition	Network change	Container throughput
Zhou (2015)		✓		✓
Wang et al. (2012)	✓			✓
Munim and Haralambides (2018)	✓			✓
Trujilo et al. (2018)	✓			✓
Wu and Yang (2018)	✓			✓
Yang et al. (2019)	✓			✓
Kawasaki et al. (2020)	✓	✓		✓
Kaluza et al. (2010)			✓	
Ducruet and Notteboom (2012a)			✓	
Montes et al. (2012)			✓	
Ducruet (2016)			✓	
Fang et al. (2018)			✓	
Mou et al. (2018)			✓	
Wu et al. (2019)			✓	
Guerrero et al. (2022)			✓	
This dissertation	✓	✓	✓	✓

CHAPTER 3: Evaluation of Hanshin port cooperation in a maritime network

3.1 Introduction

3.1.1 Port cooperation between Kobe and Osaka port

This chapter is to reveal the effectiveness of port cooperation for competition in an international maritime network, as mentioned in Chapter 1. We focus on the change in the Hanshin port that results from building cooperative relationships in a complex network. Figure 3.1 shows the amount of transshipment cargo to/from Japan via the Kobe, Osaka, or Busan ports and the location of each port.

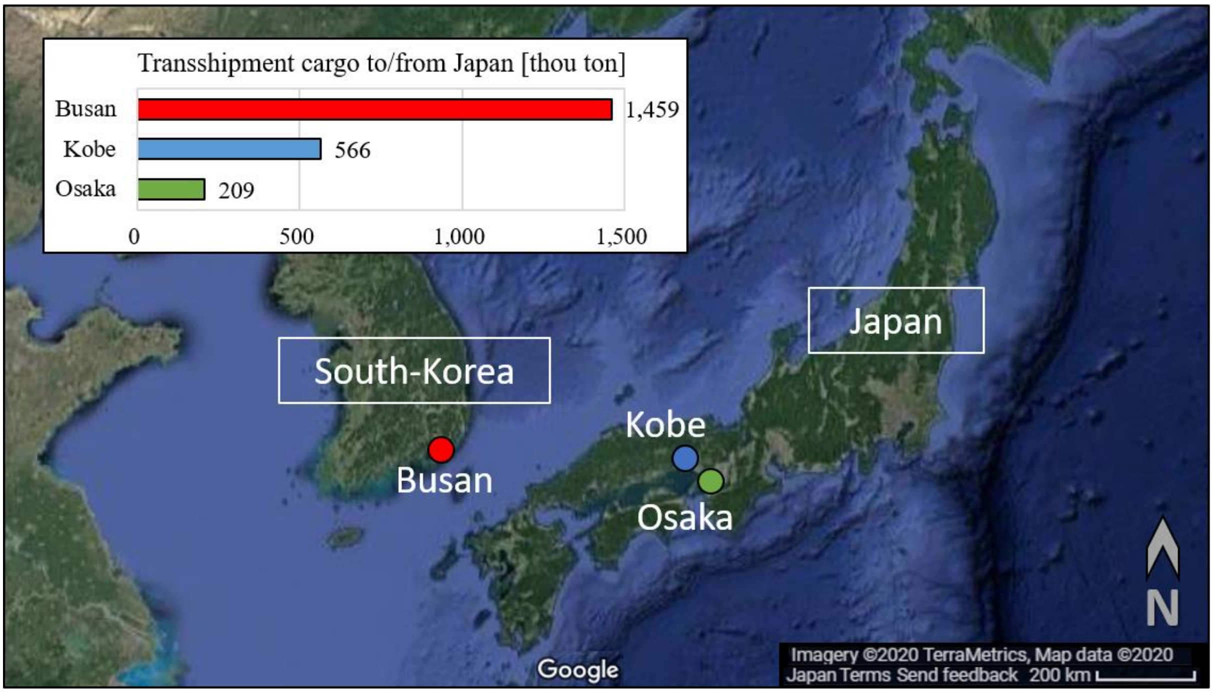


Figure 3.1 Port locations and amount of transshipment cargo to/from Japan in November 2008

As shown in Figure 3.1, the Japanese transshipment cargo in Kobe and Osaka is lower than in Busan, which indicates the competitiveness of Kobe and Osaka ports are inferior to Busan port. Thus, the Japanese government launched a policy for the International Container Strategic Port (ICSP) in 2009. The ICSP policy is to realize the cooperation between Kobe and Osaka to create the aggregated Hanshin port, which aims to increase the competitiveness of the Hanshin port and promote transshipment at Hanshin instead of Busan. This cooperation was managed by a joint management company called the Kobe-Osaka International Port Corporation, established in 2014. The joint management company intended to (1) effectively develop terminals without duplication, (2) respond more flexibly to market needs and changes, (3) strengthen bargaining powers to shipping lines, and (4) provide more port service choices among shippers (Inoue 2018). The cooperation was expected to obtain synergistic effects, including resource utilization and cost reduction with economies of scale, via integrated management as a large-scale port. However, the joint management company has not realized the overall business plan for both Kobe and Osaka due to the limited discretionary decision-making powers regarding port management. The port management and planning have been separately conducted by Kobe and Osaka cities as part of each city's management. Figure 3.2 shows the relationship between Kobe and Osaka ports. This indicates that the synergistic effects of port cooperation were not entirely achieved (Inoue 2018, Kawasaki et al. 2020). A simple comparison before and after the ICSP policy cannot completely reveal the impact of synergistic port cooperation on port hierarchy.

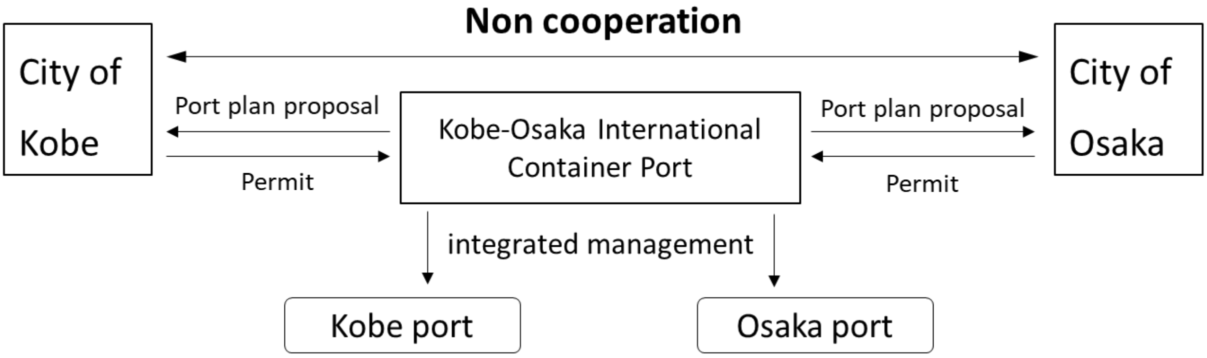


Figure 3.2 Relationship between Kobe and Osaka ports

3.1.2 Research framework

This chapter analyzes an undirected and weighted network based on the Nationwide Flow Survey of Export-Import Container Cargos in 2008 and 2018 in Japan (MLIT, 2009 and 2019). The survey aimed to comprehend the container flow of exports and imports from/to Japan and report Japanese container cargo in November once every five years. From the survey, we can clarify the origin, destination, and transshipment port of container cargo to/from Japan. A graph is made with ports as nodes, and undirected links are weighted by the amount of container flow.

As mentioned in Chapter 3.1.1, the simple comparison between networks in 2008 and 2018 cannot completely reveal the impact of synergistic port cooperation on port hierarchy. Therefore, we prepared two types of networks in 2018: without and with synergistic effects. The first network includes the Kobe and Osaka ports as separate nodes and is defined as the network without full synergistic effects due to the separate operation of each port. The second network was reorganized by aggregating the links connected to the Kobe and Osaka ports to new nodes as the Hanshin port, defined as the network with synergistic effects. This is because it represents the aggregated port and has the potential to enjoy full synergistic effects, such as resource utilization and cost reduction, as a large-scale port. The separated and aggregated networks are called "2018 (Base)" and "2018 (Coop)," respectively. Figure 3.3 shows the image of the network in 2018 (Base) and 2018 (Coop).

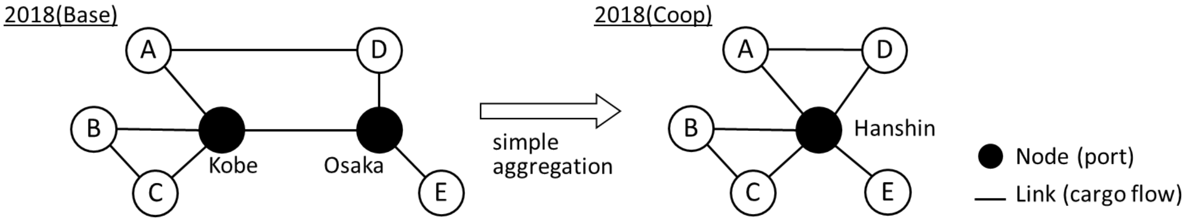


Figure 3.3 Image of network in 2018(Base) and 2018 (Coop)

First, we compare the networks in 2008 and 2018 (Base) to comprehend the actual situation of network transition, which includes the impact of port cooperation and other influential factors, such as the new terminal in Busan, Korea. This comparison is based on complex network measures, such as node strength. Second, we compare 2018 (Base) and 2018 (Coop) networks to show the expected impact of a highly synergistic port cooperation. This comparison is based on complex network measures, such as centrality. Additionally, we implement the link predictions that determine future connections to reveal the difference in the network by the synergistic cooperation.

3.1.3 Objectives

The main objective of this chapter is to reveal the effectiveness of port cooperation for competition in the international maritime network. We set two objectives as follows;

Objective 3.1: To evaluate how has the current port cooperation between Kobe and Osaka ports affected the competitiveness

Objective 3.2: To explore the impact of port cooperation as a simple aggregation in network

Objective 3.1 is achieved by comparing networks in 2008 and 2018 (Base). We evaluate whether the current cooperative policy in ICSP realizes stronger competitiveness in Hanshin port than in Busan port. Objective 3.2 is achieved by comparing networks in 2018 (Base) and 2018 (Coop). We analyze the impact of synergistic cooperation on competitiveness.

3.2 Methodology

This chapter analyzes the three Japanese cargo networks with complex measures and link prediction.

3.2.1 Complex network measures

An undirected and weighted network (G) consists of two sets: the set of nodes as ports $(\mathcal{N})$ and the set of links as the connection between ports $(\mathcal{L})$. We define the number of nodes as N and refer to a node by its order i in the set $\mathcal{N}$ $(\mathcal{N} \equiv \{n_1, n_2, \dots, n_i, \dots, n_N\})$. Additionally, we define the number of links as L and refer to its order i in the set $\mathcal{L}$ $(\mathcal{L} \equiv \{l_1, l_2, \dots, l_i, \dots, l_L\})$. The two nodes connected by a link are referred to as adjacent or neighboring nodes. The network $G = (\mathcal{N}, \mathcal{L})$ can be expressed by its adjacency matrix A, which is an $N \times N$ square matrix with entries a_{ij}. If the link between nodes i and j exists, entry a_{ij} is 1; otherwise it is 0. The intensity of the connection between nodes i and j is defined as weight w_{ij}. This study analyzes the links weighted by the amount of container flow between ports. The configuration of network G is identified with the following topological aspects.

The degree (k_i) of node i is the number of links connected to its node, which can be calculated using:

$$k_i = \sum_j a_{ij} \tag{3.1}$$

The degree is a measure counting for each port the number of connections to other ports. In maritime transport, a degree would highlight possible transfer steps in the ports, indicating the ports' connectivity (Ducruet et al., 2010).

We express the scale-free structure, which is one of the basic topological properties of a network, using the probability distribution of degree $P(k)$. Scale-free networks have an inhomogeneous degree distribution with a few nodes connected to many other nodes (hub) and many poorly connected nodes (Boccaletti et al., 2006). A network is a scale-free network in the case where a network exhibits a power-law degree distribution $P(k) \propto k^{-\gamma}$. As the value of the power-law coefficient γ increases, the ratio of hubs in the network decreases, and the ratio of poorly connected nodes increases.

Each node is characterized by a strength (s_i) that indicates how strongly it is connected with the network. The strength s_i is the sum of the weights of links connected to the node and can be calculated using:

$$s_i = \sum_j w_{ij} \tag{3.2}$$

We calculate the heterogeneity of the weights of links on the node with a disparity quantity (v_i) as follows:

$$v_i = \sum_j \left(\frac{w_{ij}}{s_i}\right)^2 \tag{3.3}$$

If all links have equal weights, all weights become the strength value divided by degree (s_i/k_i) and the disparity value becomes $1/k_i$. If several links dominate the node, the disparity value becomes larger and closer to 1 (Boccaletti et al., 2006).

Community structures are subsets of highly interconnected nodes in the network G. Nodes in a community connect with many nodes in the same community and with a few nodes in different communities. A smooth container flow is achieved within a community. We detect communities to maximize modularity (Q) that measures the density of links inside communities (Newman and Girvan, 2004) and is expressed as:

$$Q = \frac{1}{2m}\sum_{i,j}\left[w_{ij} - \frac{s_i s_j}{2m}\right]\delta(o_i, o_j) \tag{3.4}$$

where o_i is the community to which node i belongs. The function $\delta(o_i, o_j)$ takes a value of 1 if nodes i and j belong to the same community $(o_i = o_j)$ and $m = (\sum_j w_{ij})/2$; otherwise, it is 0. The maximization of modularity is solved using the Louvain algorithm, which is an agglomerative iterative algorithm that takes a node and puts it into groups (Blondel et al. 2008).

The betweenness centrality (b_i) counts the participation of a given node in the shortest paths between other node pairs, and is expressed as:

$$b_i = \frac{1}{(N-1)(N-2)} \sum_{j,h} \frac{\sigma_{jh}(i)}{\sigma_{jh}} \tag{3.5}$$

where σ_{jh} is the number of shortest paths connecting nodes j and h, and $\sigma_{jh}(i)$ is the number of shortest paths connecting nodes j and h and passing through node i. Betweenness centrality expresses the influence of the flow circulating through the network (Bergamini et al., 2017) and quantifies the importance of individual nodes in a network (Boccaletti et al., 2006). In maritime transport, the centrality reflects their ability to connect various scales from the local to the global, which indicates the accessibility of ports (Ducruet et al., 2010). Note that the weights of the links do not influence the centrality.

3.2.2 Link prediction

This study predicts two types of links that affect the port hierarchy of cooperative ports: maximizing centrality and high probability. Maximizing centrality indicates the links that maximize the centrality of the given nodes by connecting them. We applied a greedy algorithm to derive links to maximize the betweenness centrality of the Kobe and Osaka ports in the 2018 (Base) network or the Hanshin port in the 2018 (Coop) network.

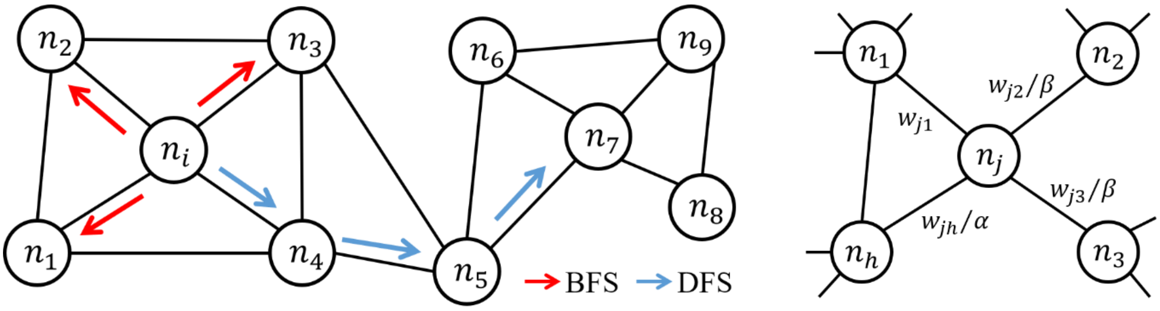
A high probability indicates the links that have a high probability of connecting to a given node based on the network configuration, such as existing links and node proximity. The derivation of high probability links is known as link prediction. We applied a logistic regression to predict high probability links, which considers the various features in the link prediction (Ma et al., 2017). The features of links required in link prediction are derived via graph embedding, which converts a graph into a low-dimensional space while preserving the graph information (Cai et al., 2018). This study applies the node2vec method proposed by Grover and Leskovec (2016) as the graph embedding method. Node2vec treats the problem of representing a graph structure as a machine learning task using a data-driven approach. Compared to the traditional approach that derives graph embedding using hand-engineered features, node2vec is less time consuming and more economical (Hamilton et al., 2017). The link predictions using node2vec in the 2018 (Base) and 2018 (Coop) networks are expected to reflect changes in the network structure. The comparison shows the change from building cooperative relationships, such as network proximity and structural similarity.

3.2.2.1 Node2vec

Node2vec is a graph embedding method that is categorized as a random walk approach. Node2vec explores feature representations that maximize the likelihood of preserved network neighborhoods (Grover and Leskvec 2016). We define $f: \mathcal{N} \longrightarrow X \in \mathbb{R}^{N \times p}$ as the function from nodes to feature representations. We embed each node into a p dimension vector as the feature representation and then group it into a feature matrix X. The probability of the network neighborhood of a node $i\left(Ns(n_i)\right)$ observed through a neighborhood sampling strategy is maximized in node2vec. Its feature representation is denoted as f and is expressed as:

$$\max_f \sum_i \log P\left(Ns(n_i) \middle| f(n_i)\right) \tag{3.6}$$

Node2vec exploits two types of random walks based on breadth-first sampling (BFS) and depth-first sampling (DFS) to capture two types of similarities: structural roles and community structure. Structural roles indicate the structural functions of ports in liner shipping networks, such as a hub or gateway port (Wilmsmeier and Notteboom, 2011). Community structure results from sharing denser relations with each other due to spatial proximity (Ducruet and Zaidi, 2012). In BFS, random walks are mainly limited to exploring a node's neighborhood and are effective in capturing structural roles. In DFS, random walks explore further away from the node and are effective in capturing community structure (Grover and Leskovec, 2016).



(a) (b)

Figure 3.4 Random walks in node2vec: (a) Differences in random walks in BFS and DFS, and (b) a biased random walk

Source: Grover and Leskovec (2016), modified by author

The biased transition probability $\left(P\left(r^t = n_i \middle| r^{t-1} = n_j\right)\right)$ realizes two types of random walks. Figure 3.4 (a) shows the differences in random walks in BFS and DFS. Figure 3.4 (b) and Equation 7 show the transition probability from node j in the random walk after the transition from nodes h to j.

$$P\left(r^t = n_i \middle| r^{t-1} = n_j\right) = \begin{cases} w_{ji}/\alpha M & if\ w_{ji} \neq 0\ and\ d_{hi} = 0 \\ w_{ji}/M & if\ w_{ji} \neq 0\ and\ d_{hi} = 1 \\ w_{ji}/\beta M & if\ w_{ji} \neq 0\ and\ d_{hi} = 2 \\ 0 & otherwise \end{cases} \tag{3.7}$$

where r^t is the *t*-th node in the walk and M is the normalizing constant. The transition probability depends on the weight between nodes i and j, two parameters (α, β), and distance (d_{hi}), which is defined as the number of links in the shortest path between nodes h and i. Parameter α controls the probability of revisiting a node in the walk, and parameter β controls whether the random walk is based on BFS or DFS. The correct balance of the two types of random walks in node2vec enables link prediction to reflect the community structure and structural equivalence between nodes (Goyal and Ferrara 2018).

3.2.2.2 Analytical setup

We adopt logistic regression to evaluate the probability of future link connections for link prediction. The independent variable of the logistic regression model is the *p* dimension feature representation vector of links $(\boldsymbol{y}_{ij})$ between nodes i and j. We define the link representation vector as the Hadamard product of the feature vector of nodes $(\boldsymbol{x}_i \circ \boldsymbol{x}_j)$ in feature matrix X, which provides the best performance in node2vec (Grover and Leskovec, 2016). The connection probability (z_{ij}) can be expressed as a sigmoid function as follows:

$$z_{ij} = \frac{1}{1 + exp\left(-\boldsymbol{y}_{ij}^T \cdot \boldsymbol{\omega} + \varepsilon\right)} \tag{3.8}$$

where $\boldsymbol{\omega}$ is the regression coefficient vector and ε is the error term.

Figure 3.5 shows the link-prediction procedure. First, we removed 300 links from the network to validate the link prediction accuracy using preventing non-linked nodes as the test data. Node2vec was applied to the removed network to obtain the node representation vectors. Link representation vectors were obtained using the Hadamard product of the node representation vectors. A logistic regression was applied to derive the connection probability of each link. Finally, the obtained connection probability was validated using the first removed links. We separately conducted the above process three times on the resampled network and combined the separate results into a single output to improve the predictive performance.

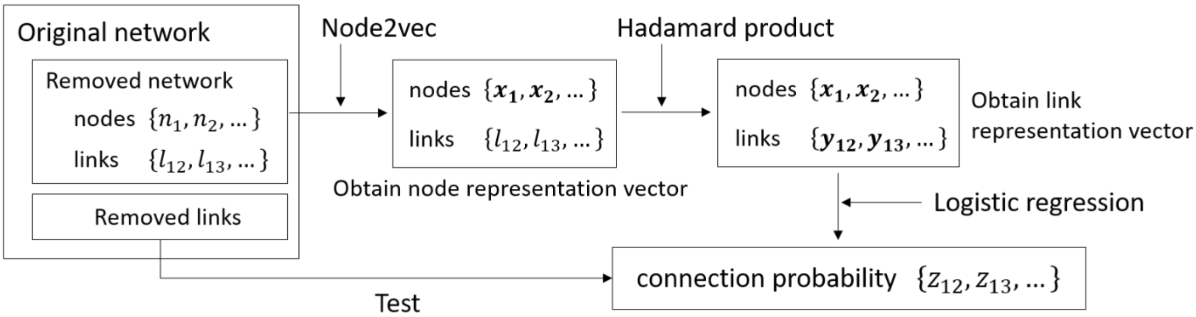


Figure 3.5 Link prediction process

The validation allows tuning of the hyperparameters, such as α and β, to obtain an optimum random walk for BFS and DFS. We explore the optimum value with a grid search over α, β ∈ $\{0.25, 0.50, 1.00, 2.00, 4.00\}$ to maximize the accuracy that measures the ratio of correctly predicted observations to total observations, which Grover and Leskovec (2016) explored. Table 3.1 shows the values of parameters α and β with the highest accuracy and F_1 scores, which are calculated by the harmonic mean of precision and recall in the binary classification evaluation, in the grid search. We set the number of walks (nl) to 15 for the other parameters, which is the number of times that a node becomes the starting node of a random walk. The length of the number of nodes visited in one random walk, the walk length (nw), was set to 10. The neighborhood size (ns) is the distance of the neighbors of a node and was set to 3. The dimension of the feature vector (p) was set to 100. Note that these parameters were determined based on the research by Grover and Leskovec (2016).

Table 3.1 Parameters $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ with the highest accuracy and $\boldsymbol{F_1}$ scores

	2018 (Base)		2018 (Coop)	
	BFS	DFS	BFS	DFS
α	0.25	0.25	2.00	2.00
β	4.00	0.25	4.00	0.50
Accuracy	0.784	0.786	0.792	0.763
F_1 score	0.766	0.774	0.805	0.775

3.3 Results and discussion

3.3.1 Comparison between networks in 2008 and 2018 (Base)

3.3.1.1 Network properties

Table 3.2 shows the properties of the 2008 and 2018 (Base) networks. The number of nodes, links, and average strengths increased from 2008 to 2018. As most of the increased nodes connect 10 or less other nodes, the average degree decreased from 2008 to 2018. This indicates that the Japanese cargo network expanded by increasing the number of trade partner ports and the trade volume to/from Japan from 2008 to 2018. Additionally, the increase of trade volume was uniform and did not occur for any specific links because the average disparity value, which is the measure of the heterogeneity of the weight of links, did not drastically change. The power-law coefficients from 2008 to 2018 (Base) also did not drastically change, with values of 0.956 and 0.959, respectively. Therefore, the inhomogeneous degree distribution known as a scale-free network, which has few hub ports and many poorly connected ports, also did not change.

The Busan port is the largest port in the region and had more than twice the degree of the largest Japanese port (Yokohama) in 2008 and 2018 (Base). Whereas the degree of Yokohama did not change significantly, the degree of Busan increased from 2008 to 2018. These results indicate that the Japanese cargo network depends heavily on foreign ports.

The Tokyo and Shanghai ports continued to be the pair with the maximum weight. This reflects the fact that China is Japan's largest trade partner and that Tokyo and Shanghai are the largest ports in Japan and China, respectively. The Japanese port pairs with maximum weight have changed over time. This weight increase indicates a change in the transshipped cargo network within Japanese ports. The Sendai-Shiogama and Hiroshima ports in Table 3.2 are local Japanese ports.

Table 3.2 Networks properties in 2008 and 2018 (Base)

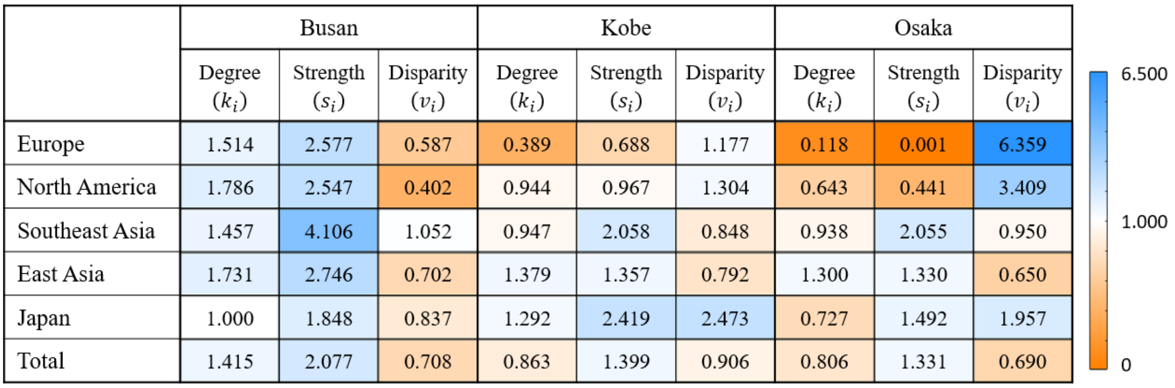
Measure	2008	2018 (Base)
Number of nodes (N)	551	686
Number of nodes - 10 or less degree	400	532
Number of links (l_i)	3,810	4,614
Average degree (k_i)	13.83	13.45
Average strength (s_i)	61,047	74,461
Average disparity (v_i)	0.463	0.485
Power-law coefficient (γ)	0.956	0.959
Maximum degree in all ports	390 (Busan)	552 (Busan)
Maximum degree in Japanese ports	163 (Yokohama)	164 (Yokohama)
Maximum strength in all ports [ton]	2,863,200 (Tokyo)	4,513,446 (Busan)
Maximum weight in all links [ton]	451,470 (Tokyo and Shanghai)	534,381 (Tokyo and Shanghai)
Maximum weight in links between Japanese ports [ton]	31,229 (Tokyo and Sendai-Shiogama)	115,851 (Kobe and Hiroshima)

3.3.1.2 Measures in each region

Figure 3.6 shows the change ratio of degree, strength, and disparity for the Busan, Kobe, and Osaka ports in each region from 2008 to 2018 (Base). The degree and strength of the Busan port increases in all regions, except for the degree in Japan. The disparity value decreased in Europe, North America, and

East Asia, indicating that an increase in low-weighted links in 2008 contributed to the increase in strength and degree in 2018 (Base). Conversely, Southeast Asia had the largest increased ratio of strength in the other regions. The change ratio of disparity is 1.052 from 2008 to 2018 (Base), which indicates that a uniform and drastic increase occurred in Southeast Asia. These results, combined with the total increase in degree and strength, indicate that the Busan port contributed to the expansion of the Japanese cargo network.

The degree and strength of the Kobe and Osaka ports decreased in North America and Europe. In particular, the degree and strength of Osaka drastically decreased in Europe and caused a high disparity value. This result indicates that the key objective of the ICSP policy to maintain and expand the number of ports of call of the trunk line was not achieved. However, the degree of Kobe and the strength of Kobe and Osaka have increased in Japan. Thus, the objective of the ICSP policy to expand transshipment to/from Japan appears to have been achieved. This is evident because the degree and strength represent the number of connected ports and the amount of container flow. The increasing disparity values of Kobe and Osaka indicate that the increases in strength in Kobe and Osaka using the ICSP policy were only achieved for some ports. Additionally, the increased strength in the Southeast and East Asian ports contributed to the increase in total strength for Kobe and Osaka.



	Busan			Kobe			Osaka		
	Degree (k_i)	Strength (s_i)	Disparity (v_i)	Degree (k_i)	Strength (s_i)	Disparity (v_i)	Degree (k_i)	Strength (s_i)	Disparity (v_i)
Europe	1.514	2.577	0.587	0.389	0.688	1.177	0.118	0.001	6.359
North America	1.786	2.547	0.402	0.944	0.967	1.304	0.643	0.441	3.409
Southeast Asia	1.457	4.106	1.052	0.947	2.058	0.848	0.938	2.055	0.950
East Asia	1.731	2.746	0.702	1.379	1.357	0.792	1.300	1.330	0.650
Japan	1.000	1.848	0.837	1.292	2.419	2.473	0.727	1.492	1.957
Total	1.415	2.077	0.708	0.863	1.399	0.906	0.806	1.331	0.690

Figure 3.6 Change rations of each measure from 2008 to 2018(Base)

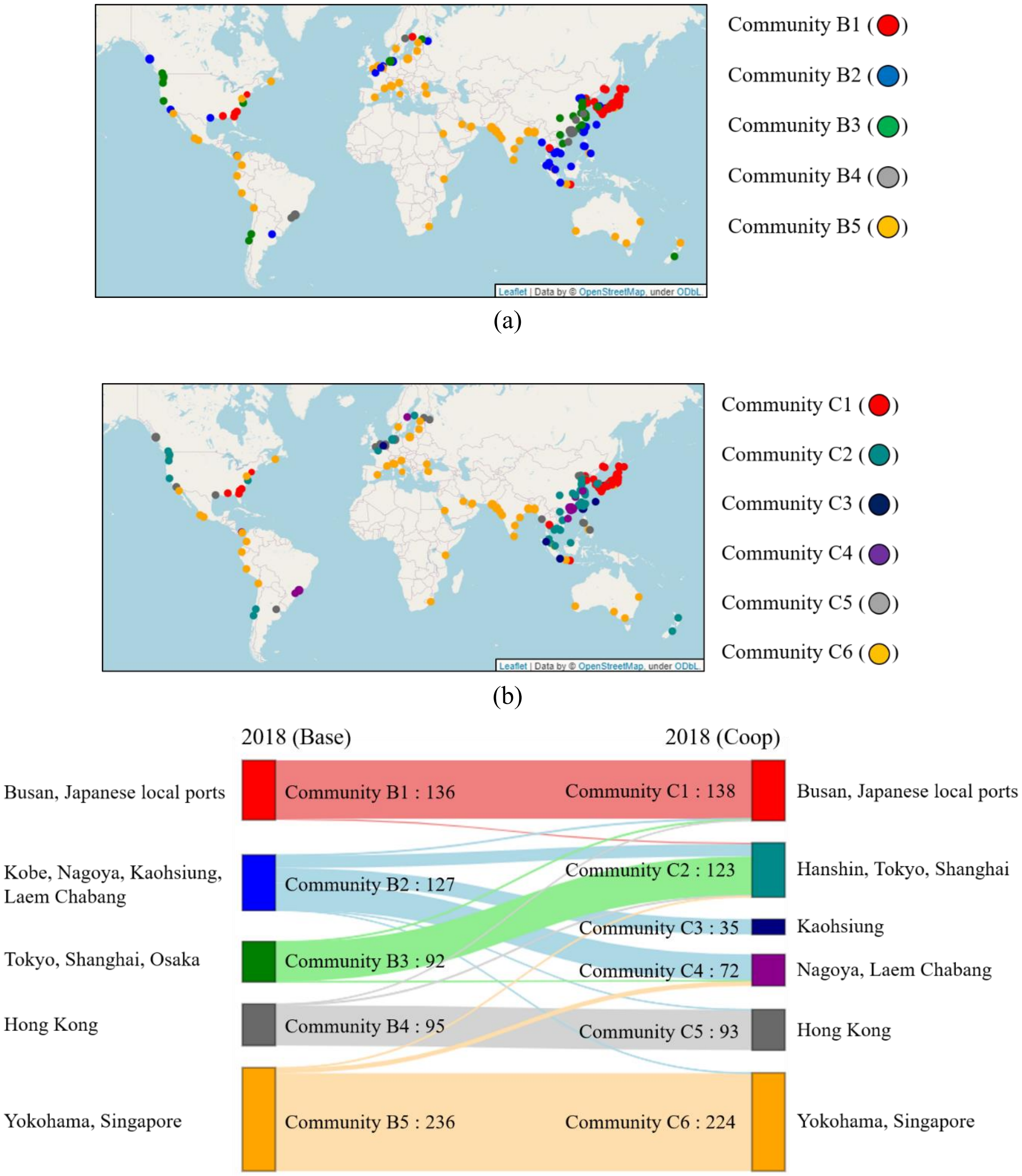
3.3.2 Comparison between networks in 2018 (Base) and 2018 (Coop)

3.3.2.1 Community structure

Figure 3.7 shows community structures, which indicate highly interconnected ports by maximizing modularity and is one of the complex network measures. Figures 3.7 (a) and (b) show the communities of the top two hundred ports with the highest strength values in 2018 (Base) and 2018 (Coop) networks, respectively. The breakdown of each community is shown in the graph structure in Figure 3.8. Figure 3.7 (c) shows the change of ports in communities as a Sankey diagram. The 2018 (Base) network has five communities, as shown in Figure 3.7 (a). In this figure, Kobe belongs to community B2, which includes the Southeast Asian ports, and Osaka belongs to community B3, which includes the East Asian ports. The community structure shows a higher interconnection with Asian ports than ports belonging to the trunk line, such as the North American and European ports.

The differences between communities in 2018 (Base) and 2018 (Coop) indicate that building a cooperative relationship to create the Hanshin port affected the communities. Specifically, by combining B2 community ports, which included Kobe, with most community B3 ports, which included Osaka, the Hanshin port now belong to the new C2 community in 2018 (Coop), as shown in Figure 3.7 (c). The Hanshin port is highly interconnected with the Southeast and East Asian ports, as shown in Figure 3.7 (b). The remainder of the ports that belonged to the B2 community in 2018 (Base) now create two new smaller communities, C3 and C4, in 2018 (Coop). These results indicate that Kobe worked as a bridge to connect the ports belonging to communities C3 and C4 with high interconnection in 2018 (Base). The Hanshin cooperation achieves a higher inter-connection with B3 community ports than with C3 and C4 community ports and does not work as a bridge.

The communities that the cooperative ports did not belong to in 2018 (Base) did not change with the cooperation, such as B1, B4, and B5. In particular, the Busan port belongs to communities B1 and C1 with many Japanese local ports in 2018 (Base) and 2018 (Coop). The cooperation did not construct interconnected relationships with Japanese local ports that were higher than with the Busan port. The higher position of Kobe and Osaka in the Japanese cargo network port hierarchy compared to the Busan port was not achieved by the aggregation as port cooperation in terms of community.

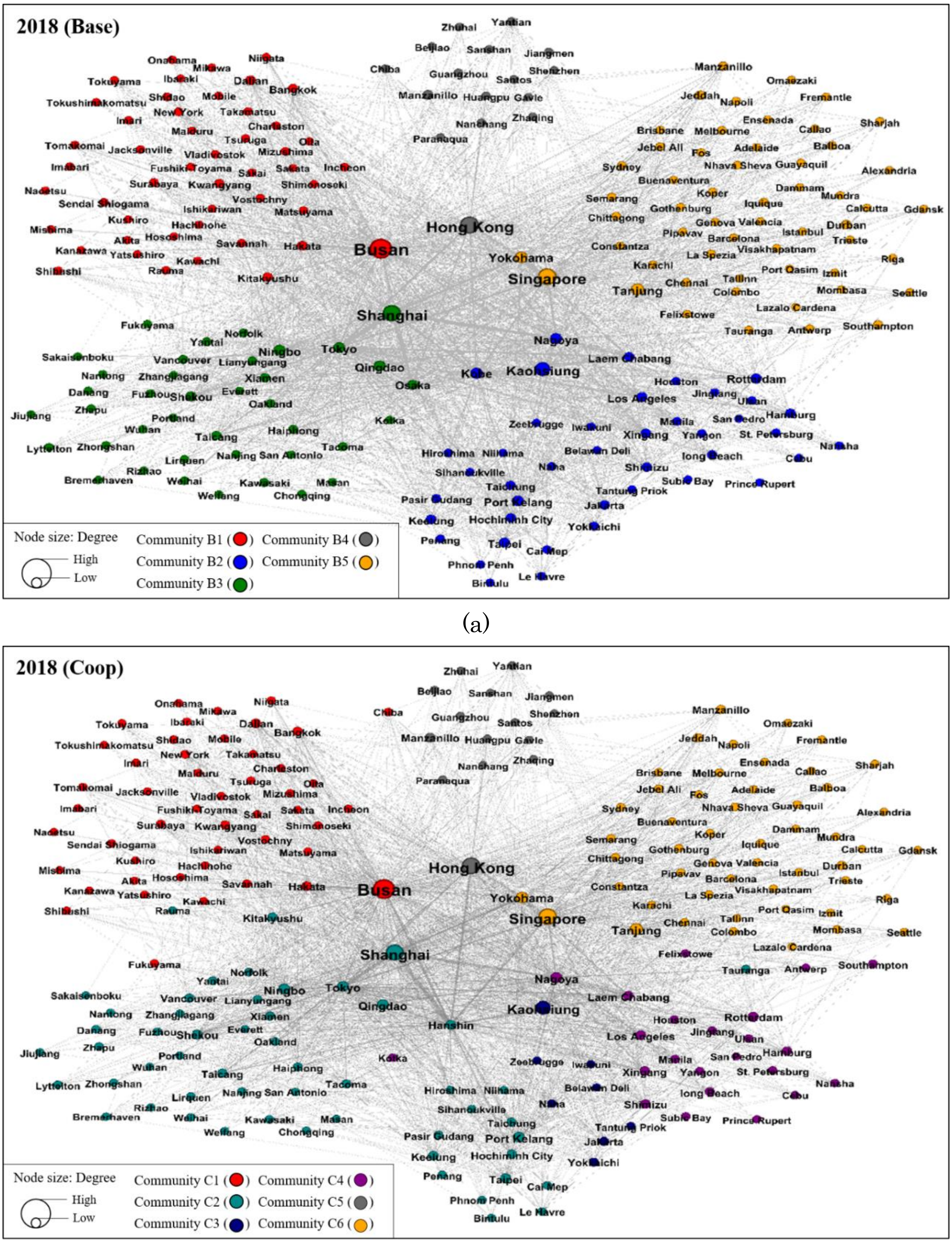


(a)

(b)

(c)

Figure 3.7 Community structures of Japanese cargo networks: (a) Community of ports in 2018 (Base), (b) community of ports in 2018 (Coop), and (c) change in the number of ports belonging to each community



(a)

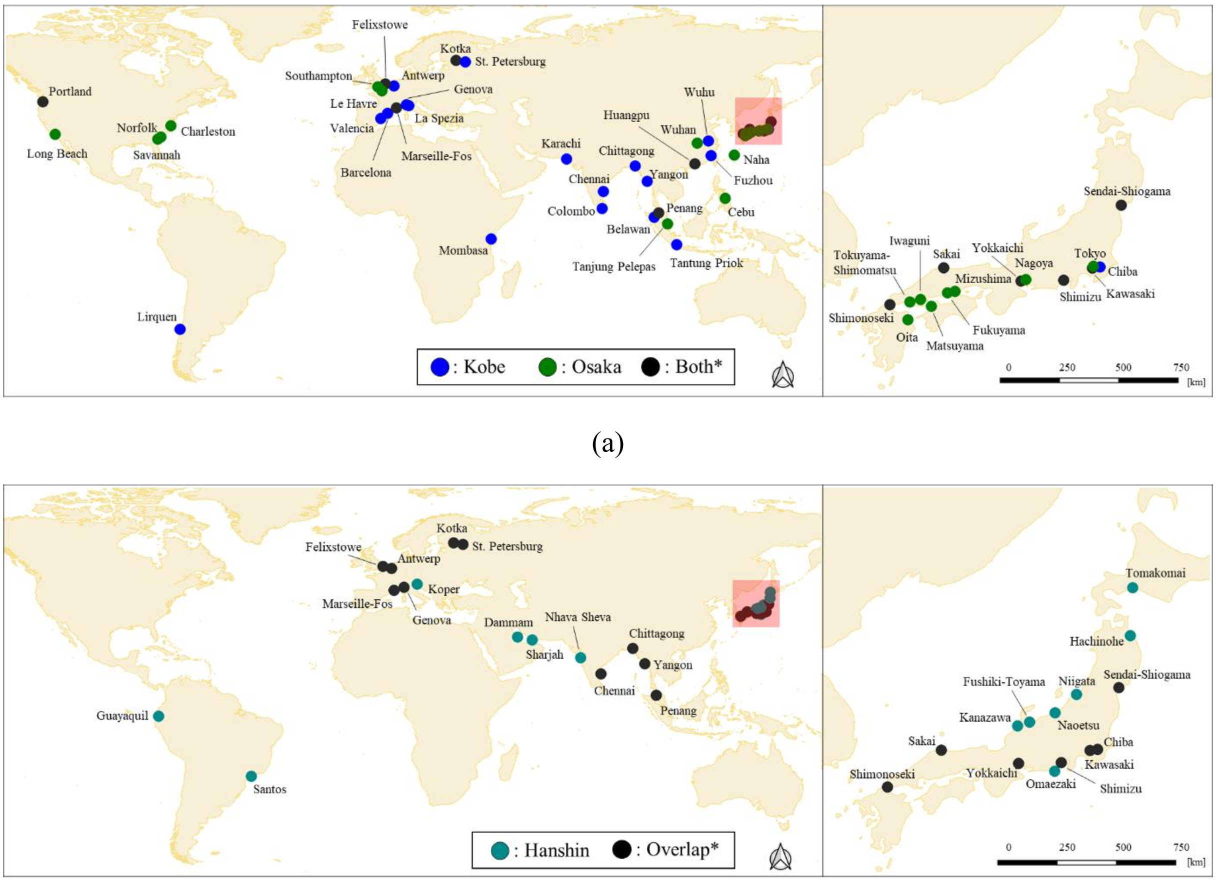
(b)

Figure 3.8 Visualization of the community as the graph (a) 2018 (Base) (b) 2018 (Coop)

3.3.2.2 Link prediction

Figure 3.9 shows the top 30 link prediction results for ports with a high probability of connecting a given node based on the network configuration. The high probability ports that connect to Kobe are spread all over the world, as shown in Figure 3.9 (a). In particular, the number of European and South Asian ports is larger than in other regions. If we consider the policy to attract new services by focusing only on the

Kobe port, shipping services to European ports via South Asian ports are easily achieved due to the high probability of connecting. As for the Osaka port, the high probability ports that connect are in North America or East Asia, including Japan. Shipping services to North American ports are easily achieved for the Osaka port with the expansion of the feeder. These results indicate that the main objective of the ICSP policy, to expand the trunk line, can be achieved in the present cooperation by separating Kobe and Osaka to connect to Europe and North America, respectively.



(a)

(b)

Figure 3.9 Ports with top-thirty connection probabilities: (a) 2018 (Base) *Both: Prediction results are obtained in both Kobe and Osaka ports, and (b) 2018 (Coop). *Overlap: Overlapped prediction results in Hanshin and Kobe or Osaka ports.

Figure 3.9 (b) shows ports with a top-thirty connection probability to the Hanshin port in the 2018 (Coop) network. Changes in network configurations, such as aggregation causing changes to community structure, resulted in several ports having a high probability of connecting to Hanshin but not to Kobe or Osaka. Specifically, high probability ports include West Asian or local Japanese ports. This indicates that a different policy to attract new services should be launched when building cooperative relationships due to the different connection probabilities. However, in this case, there are several high probability ports in Europe and South Asia, similar to Kobe. As a result, shipping services to European ports via South Asia and the Hanshin port are easily attained, similar to Kobe.

3.3.2.3 Centrality measure

Table 3.3 shows the degree and betweenness centralities in the networks. In a comparison of the original results for 2018 (Base) and 2018 (Coop), the degree and betweenness centrality were increased by port cooperation. By building synergistic cooperation as node aggregation, the connection of Hanshin port with other ports expanded and contributed to its hierarchical increase in the Japanese cargo network. However, the increase of degree in Kobe is not as large; specifically, it only increased from 139 to 149 (7.2%). This indicates that most ports connected to Osaka are also connected to Kobe. The cooperation as Hanshin did not realize higher connectivity than Busan. This less connectivity in turn results in less betweenness centralities than Busan. A higher port hierarchy position for Hanshin compared to Busan was not achieved by cooperation as node aggregation alone.

Table 3.3 Measures in the networks without newly connected links (original) or with high probability or maximum betweenness links

			Busan	Kobe	Osaka
Degree (k_i)	2018 (Base)	Original	552	139	83
	2018 (Coop)	Original	551	149	
Betweenness centralities (b_i)	2018 (Base)	Original	0.372	0.023	0.006
	2018 (Coop)	Original	0.372	0.029	
	2018 (Base)	High probability at Kobe	0.372	0.024	0.006
		Max. betweenness at Kobe	0.371	0.032	0.006
		High probability at Osaka	0.372	0.023	0.006
	2018 (Coop)	Max. betweenness at Osaka	0.372	0.023	0.014
		High probability at Hanshin	0.372	0.029	
		Max. betweenness at Hanshin	0.371	0.038	

* Underlined values represent increases from the original

Table 3.3 also shows the betweenness centralities of the Kobe, Osaka, and Busan ports when the links to the ports with maximizing centrality or high probability at each port are connected. We selected five ports that maximize each centrality or have the highest connection probability at the Kobe or Osaka ports, as shown in Appendix A. There are clear differences in the betweenness centrality in the network when connecting the links. Specifically, the betweenness centralities in the network with high probability links do not drastically change from the original. Conversely, the high connection probability ports are effective for improving the betweenness centrality in 2018 (Base) and 2018 (Coop) networks. These results indicate the importance of choosing connecting nodes to achieve a higher position in the port hierarchy within the network, regardless of the cooperative relationships.

3.3.3 Discussion

Based on the results reported in the previous section, the findings of this study regarding the impact of port cooperation on port hierarchy can be summarized as follows.

First, the Japanese cargo network expanded while maintaining an inhomogeneous degree distribution from 2008 to 2018 (Base). In the expansion, the transshipped cargo to/from local Japanese ports increased in the Kobe and Osaka ports. However, the degrees in Kobe and Osaka decreased, and the expansion of the trunk line in Kobe and Osaka was not achieved. As for the strong competitor, the degree and strength of the Busan port increased in almost all regions. This indicates that Kobe and Osaka did not realize higher connectivity than Busan from 2008 to 2018. It is worth noting that the change from 2008 to 2018 was affected by port cooperation in the ICSP policy as well as other influential factors, such as the new terminal in Busan.

Second, building synergistic cooperation via node aggregation at the Hanshin port affected the higher interconnection of community structure and achieved higher centrality in the Japanese cargo network. This indicates that port cooperation affected the network configurations and contributed to a higher position in the port hierarchy. However, cooperation through port aggregation alone is not enough to realize higher connectivity because most ports connected to cooperative ports are overlapped. The cooperation did not construct higher interconnected relationships with local Japanese ports and did not attain higher centralities than the Busan port. Additionally, considering the difficulties in building a cooperative relationship, such as the governance change suggested by Yoshitani (2018) and Knaz (2018), cooperation is not the best solution to competition with a strong competitor. Accordingly, at least additional port strategies that can enjoy fully synergistic effects are needed.

Finally, the change in network configuration from cooperation affects the connection probability of the ports. Specifically, the Osaka port has high probability ports in North America and East Asia, including Japan, while the Kobe and Hanshin ports have high probability ports in Europe and South Asia. The policy to attract new services is changed by building cooperative relationships because of the different connection probabilities. However, connecting with a higher connection probability in a graph does not always effectively strengthens centrality. The connecting ports need to be selected to attain a higher position in the port hierarchy, whether building cooperation or not.

3.4 Conclusion

The objective of this chapter is to reveal the effectiveness of port cooperation for competition in the international maritime network. We set two objectives as Objective 3.1 and 3.2. Objective 3.1 is to evaluate how the current port cooperation between Kobe and Osaka ports has affected competitiveness. Objective 3.2 is to explore the impact of port cooperation as a simple aggregation in the network.

This chapter analyzed the cooperation of the Hanshin port (Kobe and Osaka) to evaluate the impact of port cooperation on the network. We applied network analysis to the Japanese cargo network, which included several complex network measures and link predictions. The Japanese cargo network was constructed as a graph with ports as nodes and undirected links weighted by the amount of container flow. Three networks were analyzed, including 2008, 2018 (Base), and 2018 (Coop). We compared the 2008 and 2018 (Base) networks to determine the impact of the ICSP policy to achieve objective 3.1. Furthermore, we compared 2018 (Base) and 2018 (Coop) networks to demonstrate the expected impact of port cooperation in the network to achieve objective 3.2.

The results suggest the following three conclusions regarding port cooperation. First, Kobe and Osaka did not attain a higher position in the port hierarchy than Busan due to connectivity. Second, although synergistic cooperation via node aggregation contributed to a higher position in the port hierarchy, additional port policies are needed to better achieve a higher position in the port hierarchy. Finally, a change in network configuration due to cooperation affects the connection probability of the ports. This study and its findings can assist policymakers engaged in port management in attaining higher positions in the port hierarchy through port cooperation. In particular, the results are valuable in areas with network configurations similar to the Japanese cargo network, which have nearby dominant hub ports, such as Busan.

This chapter has several limitations. For example, several factors other than port cooperation affected the change from 2008 to 2018. An analysis is needed to distinguish whether a network change occurred due to cooperation or other factors. Additionally, this study considered synergistic cooperation as a simple node aggregation. This aggregation does not completely reflect changes under the influence of port cooperation, such as new port calls due to cost reduction with economies of scale.

CHAPTER 4: Optimum port cooperation in different cooperative motivation

4.1 Introduction

4.1.1 Research framework

This chapter reveals the effectiveness of the port cooperation for competition from the perspective of port and shipper as the demand in maritime transport, as mentioned in Chapter 1. We derive optimum port cooperation in the two motivations, which include cooperation for regional welfare and cooperation for competition, as shown in Table 1.1. This chapter considers two cooperative issues as the optimum cooperation; cooperation level and cooperation type.

First, the cooperation level is the willingness to participate in port cooperation and to balance the competition and cooperation. The port competition is to out-perform the others to survive in the market (Luo et al., 2022), and port cooperation is to pursue a common goal by the ports (Inoue, 2018), which are important decisions of a port in dealing with its neighboring ports. A correct balance between cooperation and competition, coopetition, which is regarded as a mixture of cooperation and competition, can overcome the disadvantages of pure competitive or cooperative behaviors (Dong, 2015 and Kavirthna et al., 2019). We derive the optimum cooperation level of the optimum balance between competition and cooperation in the different motivations. The derivation of optimum cooperation level in simplified and various port situations is suitable because the cooperation level is a just benchmark for the practical cooperative strategy.

Second, the cooperation type indicates the business scope of the cooperation. Cooperation types have the following two types; port access and terminal management. We assume that cooperation reduces the cost incurred by each type. Specifically, cost reduction in port access is realized through cooperation to improve accessibility to both cooperative ports. For example, Hintjens et al. (2020) found that bundling cargo in neighboring cooperative ports could realize a modal shift to lower land transport costs, such as rail services, and identified potential regions in the EU where bundling is possible. Additionally, Los Angeles and Long Beach in the US developed an efficient rail corridor for hinterland access (Inoue, 2018). Terminal management costs are reduced through the integrated management of the two ports. For example, Kobe and Osaka in Japan established a joint management company to develop an efficient and nonduplication terminal (Inoue, 2018). We separately simulated the two types of cooperation to compare the two motivations' differences. The derivation of optimum cooperation type in specified port situations is suitable because the specified port situations can analyze detailed port strategy as the cooperation types.

We also consider the cooperation effect as a cooperation issue in addition to motivation, cooperation level, and cooperation types. Two effects of port cooperation are analyzed: improvement and higher market power. Port cooperation can reduce costs through efficiency improvements, such as preventing overcapacity and economies of scale (Donselaar and Kolkman, 2010). Regarding market power, cooperation leads to higher market power instead of less competition between cooperative ports, resulting in higher port charges (Donselaar and Kolkman, 2010 and Saeed and Larsen, 2010). In the simulation, the tradeoff about the generalized cost of shipper between cost reduction and port charge increase by the cooperation is analyzed, and we formulated to reflect these two effects. Table 4.1 summarize the four cooperative issues to consider in this chapter.

Table 4.1 Cooperation issues in Chapter 4

Cooperation level	Competition	To out-perform the others to survive in the market
	Coopetition	A mixture of cooperation and competition
	Cooperation	The pursuit of a common goal by the ports
Type	Port access	Improvement of accessibility to the ports
	Terminal management	Improvement by the integrated terminal management
Effect	Improvement	Efficiency improvement realizes cost reduction
	Market power	Higher market power results in a higher port charge

4.1.2 Objectives

The main objective of this chapter is to reveal the effectiveness of port cooperation for competition from the perspective of port and shipper as the demand in maritime transport. We set two objectives as follows;

Objective 4.1: To reveal the optimum cooperation level for different cooperative motivations

Objective 4.2: To reveal the optimum cooperation type for different cooperative motivations

As mentioned in Chapter 4.1.1, the optimum cooperation level requires a simplified model, and the optimum cooperation type requires a detailed model to analyze specific port situations. Thus, we developed two models to derive cooperation levels and types. Specifically, a game theoretical model to simulate the relationships between ports and shippers in a linear city is developed for the cooperation level in Chapter 4.2 to achieve Objective 4.1. Bi-level optimization model that is applied to a case study for the Kobe and Osaka ports in Japan is developed for the cooperation type in Chapter 4.3 to achieve Objective 4.2. Figure

4.1 shows the image of each simulation. Chapter 4.2 focuses on three ports, which include ports 1, 2, and 3 in a virtual city, considering the cooperation or competition between ports 1 and 2 and competition between ports 2 and 3, as shown in Figure 4.1 (a). Chapter 4.3 focuses on three ports, which include Busan, Kobe, and Osaka ports, considering the cooperation or competition between Kobe and Osaka in hinterland cargo and competition between Kobe and Busan in transshipment cargo.

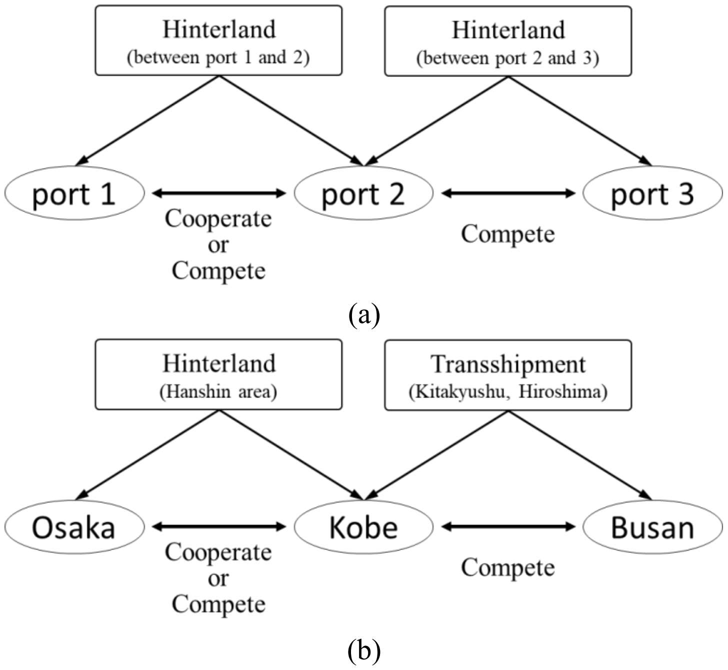


Figure 4.1 Simulation image (a) cooperation (port 1 and 2) for competition (port 2 and 3) in Chapter 4.2 (b) cooperation (Osaka and Kobe) for competition (Kobe and Busan) in Chapter 4.3

4.2 Optimum cooperation level for different cooperative motivations

This chapter derives the optimum cooperation level in various port situations by considering three cooperation issues that include motivation, type, and effect.

4.2.1 Methodology

We propose a game theoretical model with market participants, including shippers and ports. Specifically, we analyze the three ports competing or cooperating in a linear city where shippers are uniformly distributed based on the works of Zhou (2015), Wan et al. (2016), and Kawasaki et al. (2021).

4.2.1.1 Model setting

We assume that ports are gateway ports, which mainly focus on hinterland cargo and handle small transshipment cargo (Notteboom et al., 2019), because many cooperative ports motivated by cooperation for competition are categorized as gateway ports, such as the Seattle and Tacoma ports in north-western America (Inoue, 2018) and the Kobe and Osaka ports in Japan (Kawasaki et al., 2020). Wan et al. (2016) and Guo et al. (2018) explained that the hinterland and its gateway ports can generally be expressed as linear cities that have freight demand with a constant density. Thus, we simulated three ports located in a linear city, where shippers as cargo owners are uniformly distributed with a density of one shipper, as shown in Figure 4.2. Each port is located at position d_i in one-dimensional space, represented by the r-axis. Without loss of generality, we set port 2 at the central point ($d_2 = 0$). A linear city represents a market in which each port focuses and highlights the impact of port strategy changes, such as cooperation or competition, on shippers with simplified calculations. Shippers located in the area between the two ports, called a competitive area, decide to use either port based on a comparison of their utilities. There is a shipper who is indifferent to using either port because of the same utilities, which we regard as the boundary between ports. Shippers located the outside the competitive area, called suburban area, also decide to use ports based on their utility. A specific port has a substantial competitive advantage in the suburban areas. Shippers with utilities lower than the reservation price use the port. The shipper's decision results in the occurrence of a boundary at which the most distant shipper is located, which is regarded as an edge point. For an understandable formulation, we set up ports 0 and 4 virtually to represent the boundaries as edge points. The catchment area of the ports is the area between the boundaries. The locations of boundaries can change with changes in utility caused by changes in the cooperative strategy, resulting in a change in port cargo throughput.

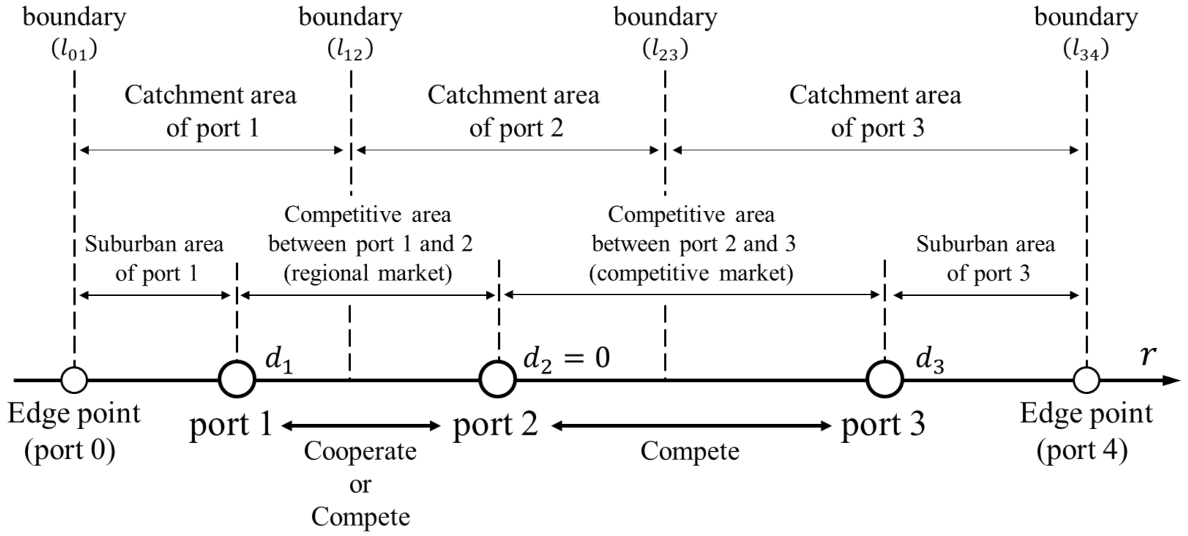


Figure 4.2 Basic setting of a linear city in Chapter 4.2

Ports cooperate or compete in linear cities. Ports 1 and 2 determine their strategies, such as cooperation or competition, when ports 2 and 3 compete. The focused market changes depending on the motivation for cooperation. Specifically, cooperation for regional welfare focuses on the market in which the shipper is located between ports 1 and 2, which we call the regional market. Ports determine cooperative strategies to increase the welfare of regions shared with cooperative ports. Cooperation for competition focuses on the market in which the shipper is located between ports 2 and 3, which we call a competitive market. Ports determine a cooperative strategy to increase cargo in a competitive market. We calculate the optimum cooperative strategy for regional welfare and competition separately and measure the difference in the obtained optimum strategy.

4.2.1.2 Model development

We applied a three-stage model in a linear city, as shown in Figure 4.3, where the cooperation level, port charge, and shippers' choice of ports are determined in this order. Specifically, in the first stage, the cooperation level parameter (z), which takes a value from 0 to 1 $(0 \leq z \leq 1)$, is introduced. If the cooperation level is zero, the two ports are completely competitive and only value their benefits in any decision. If the cooperation level is one, the two ports are completely cooperative and value the benefit of the partner port as much as they value their own in the decision. If the cooperation level is higher than 0 and less than 1, the two ports simultaneously characterize competition and cooperation, known as coopetition (Song, 2003 and Kavirthna et al., 2019). Coopetition ports value both benefits. As the cooperation level increases, the weight of the partner port's benefit increases in the decision, and the ports adopt a more cooperative strategy. It is worth noting that the value is a benchmark to make cooperative port strategy and does not any detailed and practical port strategies. The objective functions to determine the cooperative level change depending on the motivation. In cooperation for regional welfare, the surplus of the regional benefit of participants in the regional market from the complete competition between ports 1 and 2 is maximized. In cooperation for competition, the boundary between ports 2 and 3 is maximized for port 2 to obtain more cargo in the competitive market. We measure the difference in the optimum cooperation level between the two motivations.

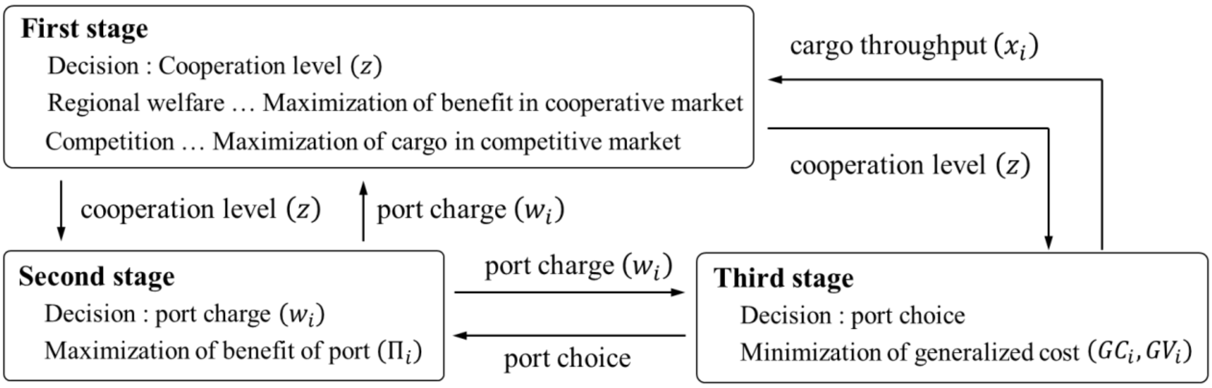


Figure 4.3 Model overview in Chapter 4.2

In the second stage, the port charge (w_i) of each port is determined to maximize its benefits. We derive Nash equilibrium to optimal charge for each port. In the third stage, the shipper determines the port to use based on the generalized cost as the utility of the port to transport its cargo. The calculation in the second and third stages are based on the decision of cooperation level in the first stage because the cooperation effect change depending on the cooperation level. Additionally, the calculation in the third stage is based on the decision of port charge in the second stage. We solve the game to drive the equilibrium of those leader-follower relationships by backward induction. We start the explanation with the third stage to fit backward induction. The notations of the model are as follows.

Notation

i, j	Port name (0 and 4 are virtual ports to identify the edge points in the formulation)
GC_i	Generalized cost for the shipper to use port *i* in a competitive area
GV_i	Generalized cost for the shipper to use port *i* in a suburb area
π_i	Regional benefit of port *i*
Π_i	Benefit of port *i*
Ir	Increment of benefit in a cooperative market (objective function in cooperation for regional welfare)

Ic	Increment of cargo in a competitive market (objective function in cooperation for competition)
Br	Benefit of regional market
V	Reservation price
l_{ij}	Boundary location between port *i* and *j*
x_i	Cargo throughput in port *i*
w_i	Port charge in port *i*
z	Cooperation level
d_i	Location of port *i*
cs	Hinterland transport cost per distance in a competitive area
cv	Hinterland transport cost per distance in a suburban area
cp_i	Cost of port *i*
ch_i	Hinterland connectivity cost of port *i*
u_i	Public level of port *i*
r	One-dimensional space as *r*-axis
α	Hinterland cost reduction ratio
β	Port cost reduction ratio
γ	Weight parameter for the benefit of market

The novelty of this model is the analysis of cooperation or competition among three ports in the game theoretical model. A previous study, for example, analyzed the factors promoting port cooperation by considering the similarity and privatization of two cooperative ports with five types of games, such as Cournot and Bertrand games (Cui and Notteboom, 2018). Trujillo et al. (2018) analyzed two Chilean ports using a Hotelling model and showed that a collusive agreement about the optimal total capacity in cooperative ports realized higher profits for both ports. The cooperative or competitive relationships between two ports using game theory have been analyzed in previous studies. The developed model in this study realizes the analysis of the influential conditions for cooperation with a third competitor, which is the contribution of this model to the previous studies.

(a) Third stage: determination of cargo throughput

In the third stage, we calculated the cargo throughput (x_i) in each port based on the shippers' choice. As previously mentioned, the shipper determines the port to use based on its utility. We calculate the utility of ports as the generalized cost. Shippers in competitive areas choose ports with lower generalized costs (GC_i). In suburban areas, shippers choose the port with a lower generalized cost (GV_i) than the reservation price (V).

Figure 4.4 shows the generalized cost of a shipper in a linear city. Equation (1) shows the generalized cost in the competitive and suburban areas for ports 1 to 3. The generalized cost consists of the port charge (w_i), hinterland transport cost (cs, cv), and hinterland connectivity cost (ch_i). Port charge represents the service price per unit charged by the port, which is determined to maximize the regional benefit in the second stage. Land transport cost represent the cost increase with distance, such as fuel or labor costs. We set different transport costs in the competitive area (cs) and the suburban area (cv). We assume that the competitive and suburban areas are near cities and rural areas, respectively. The transport cost in the competitive area is smaller than that in the suburban area because we assume that the city area has well-developed infrastructure and the required time for transportation is shorter than that for rural areas for the same distance. The distance from the port, which is calculated by the location of the shipper (r) and port (d_i), is multiplied by the transport cost per unit of distance. The hinterland connectivity cost (ch_i) represents how effectively the port can connect land and maritime transports. The hinterland connectivity cost is independent of transport distance and includes the cost to use the port *i,* such as capacity in port, container dwell times, vessel waiting time in port, and so on. Ferrari et al. (2011) emphasized the importance of connectivity to obtain larger hinterland catchment areas.

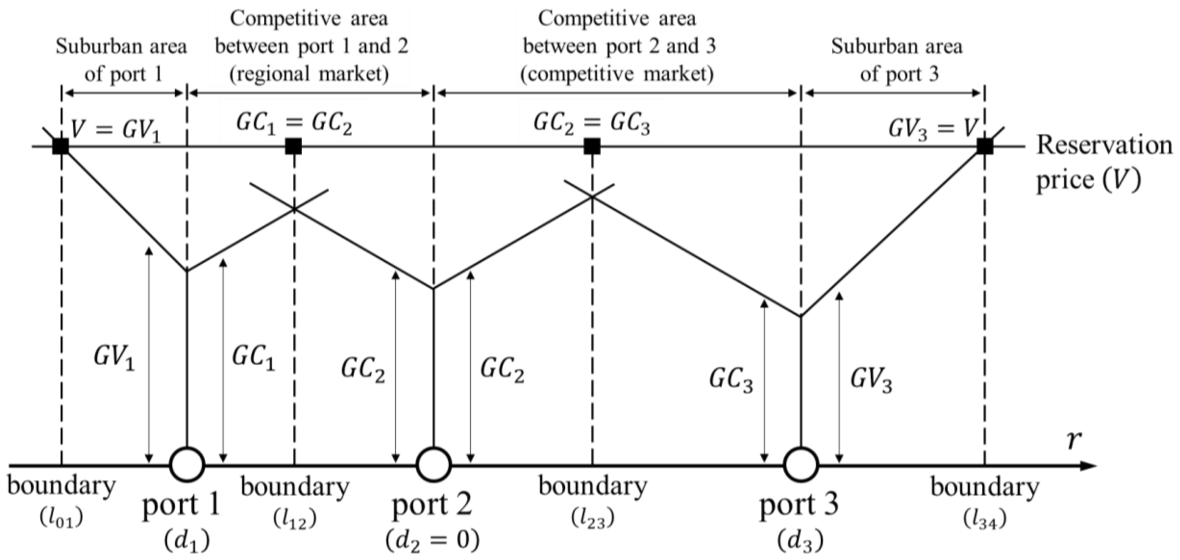


Figure 4.4 Generalized cost of shipper in the linear city

Hinterland transport and connectivity costs are reduced by improving port access through the cooperation effect in Table 4.1. We calculate the amount of cost reduction in accordance with the cooperation level (z) and the reduction ratio (α) as $(1 - \alpha \cdot z)$. We can see that the cost reduction increases as the cooperation level increases. The reduction ratio depends on the cooperation type and ranges from 0 to 1 $(0 \leq \alpha \leq 1)$.

$$\begin{aligned}
GC_1 &= w_1 + (1 - \alpha \cdot z)(cs|r - d_1| + ch_1) \\
GC_2 &= w_2 + (1 - \alpha \cdot z)(cs|r - d_2| + ch_2) \\
GC_3 &= w_3 + cs|r - d_3| + ch_3 \\
GV_1 &= w_1 + (1 - \alpha \cdot z)(cv|r - d_1| + ch_1) \\
GV_3 &= w_3 + cv|r - d_3| + ch_3
\end{aligned} \tag{4.1}$$

Shippers determine the port to be used to minimize their own generalized cost. In a competitive area, the boundary points between two adjacent ports (l_{12}, l_{23}) are where the generalized costs of both ports are the same. In suburban areas, the boundary points (l_{01}, l_{34}) are where the generalized cost and reservation price are the same (Wan et al., 2016 and Kawasaki et al., 2021). Equation (4.2) represents the boundary conditions: We calculated the boundaries with the realistic assumption that boundaries are located between the locations of each port $(l_{01} < d_1 < l_{12} < d_2 = 0 < l_{23} < d_3 < l_{34})$ based on Trujillo et al. (2018). Appendix B presents the conditions under which each value satisfies this assumption.

$$\begin{aligned}
&GC_1 = GC_2 \\
&w_1 + (1 - \alpha \cdot z)(cs(l_{12} - d_1) + ch_1) = w_2 + (1 - \alpha \cdot z)(-cs \cdot l_{12} + ch_2) \\
&l_{12} = \frac{d_1}{2} - \frac{w_1 - w_2}{(2 - 2\alpha \cdot z)cs} - \frac{ch_1 - ch_2}{2cs} \\
&GC_2 = GC_3 \\
&w_2 + (1 - \alpha \cdot z)(cs \cdot l_{23} + ch_2) = w_3 + cs(d_3 - l_{23}) + ch_3 \\
&l_{23} = \frac{d_3}{2 - \alpha \cdot z} - \frac{w_2 - w_3 + (1 - \alpha \cdot z)ch_2 - ch_3}{(2 - \alpha \cdot z)cs} \\
&V = GV_1 \\
&V = w_1 + (1 - \alpha \cdot z)(cv(d_1 - l_{01}) + ch_1) \\
&l_{01} = d_1 + \frac{w_1 - V}{(1 - \alpha \cdot z)cv} + \frac{ch_1}{cv} \\
&GV_3 = V \\
&w_3 + cv(l_{34} - d_3) + ch_3 = V \\
&l_{34} = d_3 - \frac{w_3 + ch_3 - V}{cv}
\end{aligned} \tag{4.2}$$

The cargo throughput in each port can be calculated based on the size of the catchment area because of the shipper density in the linear city. Equation (4.3) shows the cargo throughput for each port: note that cargo throughputs x_1, x_2, x_3 are guaranteed to be positive because of the assumption that boundaries $(l_{01} < d_1 < l_{12} < d_2 = 0 < l_{23} < d_3 < l_{34})$. The negative values of differentiation $\left(\frac{\partial x_1}{\partial w_1} < 0, \frac{\partial x_2}{\partial w_2} < 0, \frac{\partial x_3}{\partial w_3} < 0\right)$ indicate that the size of the catchment area and cargo throughput decrease as the port charge increases. The calculation of the differentiation is detailed in Appendix C.

$$\begin{aligned}
&x_1 = \int_{l_{01}}^{l_{12}} 1\ dr = l_{12} - l_{01} \\
&x_2 = \int_{l_{12}}^{l_{23}} 1\ dr = l_{23} - l_{12} \\
&x_3 = \int_{l_{23}}^{l_{34}} 1\ dr = l_{34} - l_{23}
\end{aligned} \tag{4.3}$$

(b) Second stage: determination of port charge

In the second stage, we calculated the port charge based on the benefit of each port (Π_i). Ports determine their charges to maximize their benefits. The port benefits consist of the regional benefits of the own port (π_i) and partner ports in the case of cooperation, as shown in Equation (4.4). The combined benefits of cooperative ports represent stronger market power that can lead to collusive agreements to make port charges higher than in the case of a completely competitive relationship, indicating that market power is an effect of cooperation (see Table 4.1). We assume that ports receive more combined benefits as the cooperation level increases.

$$\begin{aligned} &\max_{w_1} \Pi_1 = \pi_1 + z \cdot \pi_2 \\ &\max_{w_2} \Pi_2 = \pi_2 + z \cdot \pi_1 \\ &\max_{w_3} \Pi_3 = \pi_3 \end{aligned} \tag{4.4}$$

Equation (4.5) shows the regional benefits of each port: the regional benefits of a port consist of its profit from the port charge and the benefits of port users. The profits consist of the charge as revenue (w_i) and the port cost (cp_i). The port cost represents the cost increase with cargo, such as loading and unloading costs, and is reduced by cooperation in terminal management as a cooperation effect, as shown in Table 4.1. Cooperation cost reduction can be calculated using the cooperation level and the reduction ratio (β) as $(1 - \beta \cdot z)$. The reduction increased as the cooperation level increased. The reduction ratio depends on the cooperation type and ranges from 0 to 1 ($0 \leq \beta \leq 1$).

As for user benefits, we calculate the average generalized transportation cost of shippers per unit in each catchment area of the port is calculated to determine the user benefits. The average cost is composed of the sum of cost using the integral function in the numerator and the cargo throughput in the denominator, as shown in Equation (4.5). It is worth noting that we calculate the cargo throughput with the location of ports and boundaries as the size of catchment area, similar to Equation (4.3). We balanced the weight of the port profit and the average shipper cost for the benefit of the port using a non-negative parameter denoted as the public level (u_i). When the value is low, the port becomes more sensitive to its profit, demonstrating the characteristics of a private port. When the value is high, the port considers the local shipper's cost to be more important, indicating the characteristics of a public port. Other studies, such as Cui and Notteboom (2018) and Takebayashi and Hanaoka (2021), use this parameter to represent the characteristics of private and public ports. It is worth noting that the public level adjusts the unit of port profit and the average shipper cost.

$$\begin{aligned} \pi_1 &= (w_1 - (1 - \beta \cdot z)cp_1)x_1 - u_1 \left(\frac{\int_{l_{01}}^{d_1} GV_1 \, dr}{d_1 - l_{01}} + \frac{\int_{d_1}^{l_{12}} GC_1 \, dr}{l_{12} - d_1} \right) \\ \pi_2 &= (w_2 - (1 - \beta \cdot z)cp_2)x_2 - u_2 \left(\frac{\int_{l_{12}}^{0} GC_2 \, dr}{0 - l_{12}} + \frac{\int_{0}^{l_{23}} GC_2 \, dr}{l_{23} - 0} \right) \end{aligned} \tag{4.5}$$

$$\pi_3 = (w_3 - cp_3)x_3 - u_3\left(\frac{\int_{l_{23}}^{d_3} GC_3\,dr}{d_3 - l_{23}} + \frac{\int_{d_3}^{l_{34}} GV_3\,dr}{l_{34} - d_3}\right)$$

We obtained the optimum port charge (w_i) by maximizing the benefits based on first-order conditions. We solved the simultaneous equations from the first-order conditions, as shown in Equation (6). Appendix D shows the components of the coefficient matrix (A) and constant matrix (b). Appendix E shows the proof of the concavity of benefits with respect to the port charge.

$$\begin{pmatrix} \frac{\partial \Pi_1}{\partial w_1} \\ \frac{\partial \Pi_2}{\partial w_2} \\ \frac{\partial \Pi_3}{\partial w_3} \end{pmatrix} = 0 \leftrightarrow A\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} + b = 0 \leftrightarrow \begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} = -A^{-1}b \tag{4.6}$$

(c) First stage: determination of cooperation level

In the first stage, we calculate the cooperation level (z) based on the objective function for each motivation. Port 2 determines the optimum level of cooperation to maximize welfare as a surplus benefit for each market. In cooperation for regional welfare, Port 2 determines the optimum cooperation level to maximize welfare in the regional market (Ir). Welfare is the increment of benefit in the regional market (Br) from the situation where the cooperation level is 0; that is, complete competition $(Br^{z=0})$. In cooperation for competition, Port 2 determines the optimum cooperation level to maximize cargo throughput in the competitive market (Ic). We calculate the increment in the boundary between Ports 2 and 3 (l_{23}) from the complete competition $\left({l_{23}}^{z=0}\right)$ as an objective function. If no cooperation level can realize a higher objective value than the competition, the optimum cooperation level becomes zero, indicating that complete competition is optimum for them. Equation (4.7) shows the objective functions and benefits of the regional market. The benefit to the market consists of the profit and user benefits of Port 2. We weigh the profit of the ports by a weight parameter (γ), unlike the benefit of the port in Equation (4.5). This parameter represents the difference in the objective functions between the second and first stages. The port gives more weight to its port profit in the decision to determine port charge in the second stage than the decision of cooperation level in the first stage because the port charge can only be determined by the port, whereas the cooperation level should be determined by itself and the cooperating port.

Regional welfare: $\max_z Ir = Br - Br^{z=0}$

Competition: $\max_z Ic = l_{23} - {l_{23}}^{z=0}$

$$Br = \gamma(w_2 - (1 - \beta \cdot z)cp_2)(0 - l_{12}) - \frac{u_2 \int_{l_{12}}^{0} GC_2\,dr}{0 - l_{12}} \tag{4.7}$$

4.2.1.3 Input values and scenarios

In this study, we derived the optimum cooperation level for each motivation. We could not obtain clear and tractable conditions using an analytical method to reveal the differences in the optimum cooperation values owing to the complexity of the calculations. Therefore, we conducted a numerical analysis to explore the differences in optimum cooperation. Table 4.2 lists the input values for the base case. We considered realistic port situations using values based on Zhou (2015), Wan et al. (2016), and Tagawa et al. (2021), satisfying the condition of port boundaries in Appendix B. Specifically, we prepared two pairs of reduction ratios (α, β) to represent the two cooperation types: port access and terminal management. The distance between cooperative ports, which included Ports 1 and 2, was shorter than that between competitive ports, which included Ports 2 and 3, to represent the cooperation of ports in proximity. Port 3 had lower hinterland connectivity cost and port cost to represent higher competitiveness, with lower costs than Ports 1 and 2. Hinterland transport costs in competitive areas were lower than those in suburban areas because we assumed that the competitive area is near cities and has a well-developed infrastructure. Additionally, we prepared four scenarios that changed several influential values on the result to represent various realistic port situations. The model was solved in MATLAB and ran on an Intel® Core™ i5-8265 processor with 8 GB of RAM. The computation time is a few minutes.

Table 4.2 Input values for numerical analysis in the base case

			Cooperation type	
			Hinterland	Terminal
Hinterland cost reduction ratio		α	0.200	0
Port cost reduction ratio		β	0	0.200
Weight parameter for benefit of market		γ	0.200	
Reservation price		V	10.0	
Location of port	Port 1	d_1	-2.00	
	Port 2	d_2	0	
	Port 3	d_3	3.00	
Hinterland connectivity cost	Port 1	ch_1	2.50	
	Port 2	ch_2	2.00	
	Port 3	ch_3	1.50	
Cost of port	Port 1	cp_1	2.50	
	Port 2	cp_2	2.00	
	Port 3	cp_3	1.50	
Public level	Port 1	u_1	1.00	
	Port 2	u_2	1.00	
	Port 3	u_3	1.00	
Hinterland transport cost in competitive area		cs	2.00	
Hinterland transport cost in suburb area		cv	3.00	

Table 4.3 shows the four scenarios used to simulate several port situations: accessibility, competitiveness,

public, and reduction ratio. In the accessibility scenario, we changed the value of hinterland transport costs in competitive and suburban areas (cs, cv) while keeping other values the same as the base scenario. This scenario represents the effect of port accessibility on the optimum cooperation level. Wan et al. (2018) emphasized the importance of hinterland costs in port competition. In the port scenario, we changed the values of the hinterland connectivity cost (ch_2) and the port cost (cp_2). This scenario represents the cooperation impact with different levels of competitiveness on the optimum cooperation level because shippers decide to use a port that offers a lower cost and hinterland connection as a more competitive port (Yuen et al. 2012). Cui and Notteboom (2018) and Wang et al. (2012) concluded that similarity in port competitiveness, such as the level of service quality and accessibility, is an influential factor in realizing port cooperation. In the public scenario, we changed the value of the public level of Port 2 (u_2). This scenario represents the cooperation impact with different degrees of publicness on the optimal cooperation level. Cui and Notteboom (2018) and Takebayashi and Hanaoka (2021) revealed the importance of considering the degree of port publicness to realize cooperation. In the reduction scenario, we changed the values of the cost reduction ratios (α, β). This scenario represents the impact of cooperation with different cost reductions as the cooperation effect. Knatz (2018) highlighted the importance of the cooperation benefits for both ports. Note that we set the values in each scenario to satisfy the conditions of port boundary in Appendix B.

Table 4.3 Scenario overview

Name	Target	Values
Accessibility	Port access cost	cs: hinterland transport cost in competitive area $cs \in [1.00, 4.00]$ (Base:$cs = 2.00$) cv: hinterland transport cost in suburban area $cv = cs + 1.00$ (Base:$cv = 3.00$)
Competitiveness	Port competitiveness	ch_2: hinterland connectivity cost $ch_2 \in [1.00, 4.00]$ (Base:$ch_2 = 2.00$) cp_2: cost of port 2 $cp_2 = ch_2$ (Base:$cp_2 = 2.00$)
Public	Degree of publicness	u_2: public level of port 2 $u_2 \in [0, 2.00]$ (Base:$u_2 = 1.00$)
Reduction ratio	Cost reduction ratio	α: public Hinterland cost reduction ratio $\alpha \in [0.100, 0.500]$ (Base:$\alpha = 0.200$) β: port cost reduction ratio $\beta \in [0.100, 0.500]$ (Base:$\beta = 0.200$)

4.2.2 Results and Discussion

4.2.2.1 Base case

Figure 4.5 shows the objective functions for each motivation at the specified cooperation level. The functions are concave with respect to the cooperation level and reach maxima at optimum *z* values. Each motivation, which includes cooperation for regional welfare and competition, has an optimum cooperation level that maximizes the objective function, with a well-balanced combination of cooperation and competition. Although the values are small, especially in cooperation for competition in terminal management, the positive values of the objective functions indicate an increase in regional welfare and cargo throughput in competitive areas with expanded boundaries. Thus, port cooperation is an effective strategy for improving regional welfare and competition.

The optimum cooperation levels differ for different motivations for both types of cooperation. Specifically, the values of the cooperation parameter (z) in port access are 0.803 and 0.936 for regional welfare and competition, respectively. This difference indicates that cooperation for competition should adopt a more cooperative strategy than cooperation for regional welfare because ports adopt a more cooperative strategy with a higher value of the cooperation parameter. This difference in cooperation levels is due to differences in the cooperation effects for each motivation. We set the optimum cooperation level to balance the improvement and higher price with higher market power, which are cooperation effects, for each motivation. Cooperation for competition requires greater improvement to achieve high competitiveness.

Cooperation in terminal management has the opposite trend of optimum cooperation level compared to cooperation for port access, i.e., cooperation for regional welfare requires a higher level of cooperation than competition. Specifically, the values for cooperation in terminal management were 0.575 and 0.315 for regional welfare and competition, respectively. This is because regional welfare cooperation accepts higher port charges. Benefits in the cooperative market, which is an objective function of regional welfare, consist of the profit of the port and user benefit. Although a port charge increase has a negative effect on user benefits, it positively affects port profit. However, cooperation for competition requires lower port charges for higher port competitiveness, resulting in a lower optimum cooperation level. These results indicate that different cooperation effects are observed depending on the motivation and type of cooperation and highlight the importance of building different strategies for different motivations. Note that the value differences for different motivations and types were not very large. Suppose incorrect optimum cooperative strategies are constructed, such as cooperation for regional welfare, to realize the optimum cooperation level in competition without considering the difference. In that case, the results do not drastically change.

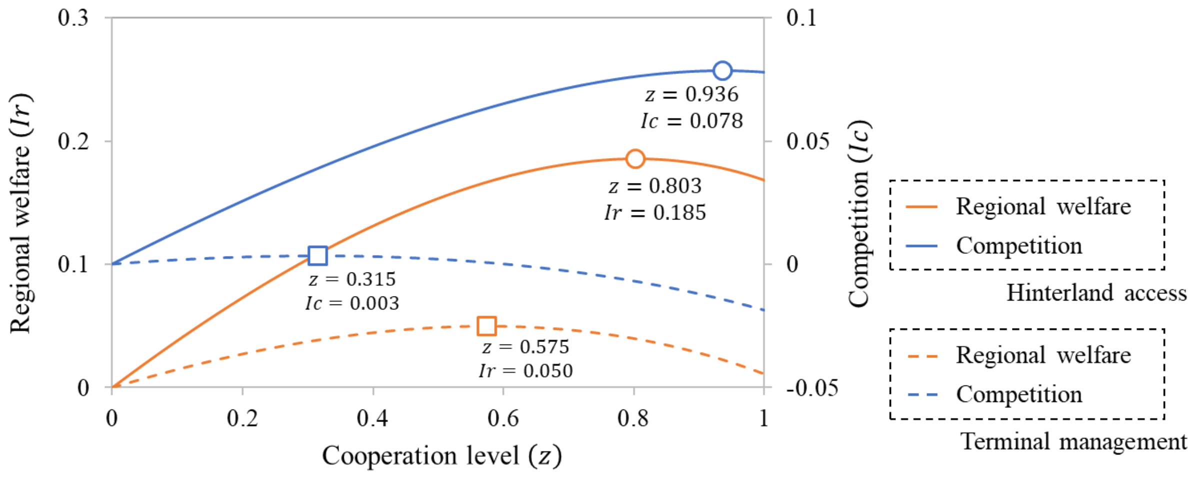


Figure 4.5 The objective function for each motivation $(\boldsymbol{Ir}, \boldsymbol{Ic})$ with cooperation level

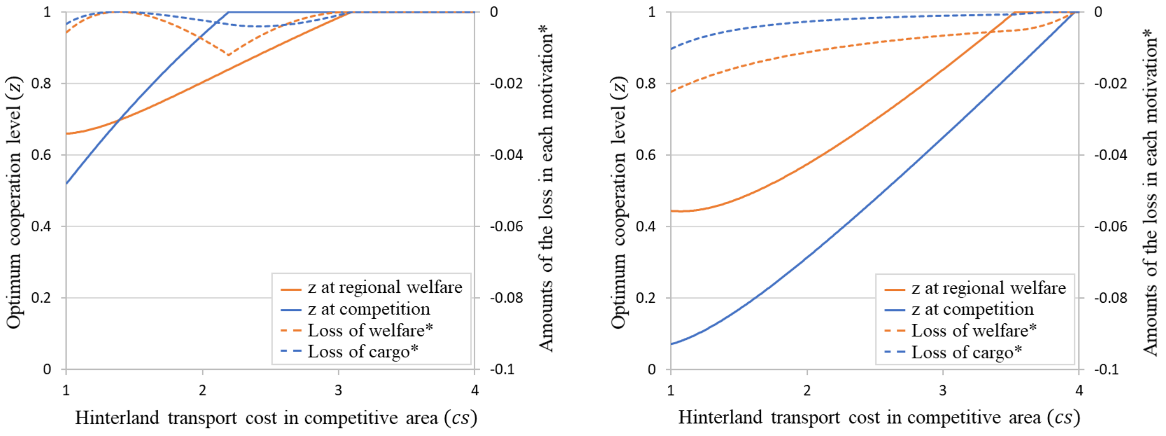
4.2.2.2 Scenario analysis

(a) Accessibility scenario

Figure 4.6 shows the optimal cooperation level for each type and motivation in the accessibility scenario. This scenario simulated the impact of port accessibility on the optimum cooperation level. Although the gradients are different, both cooperation types require a higher level of cooperation as the hinterland transport cost increases, and they require complete cooperation $(z = 1)$ for large hinterland transport costs. This indicates that different cooperative strategies should be developed for the hinterlands. Specifically, ports in areas with low transport costs and highly developed port access should develop competitive strategies. Whereas ports in areas with high transport costs and less-developed access should construct cooperative strategies.

As for the difference in motivations, the magnitude of relationships of cooperation level between different motivations change depending on cooperation type and hinterland transport cost. Specifically, Figure 4.6 (a) shows that cooperation in port access for competition requires a lower level of cooperation than cooperation for regional welfare at low hinterland transport costs. After the point at which the optimum cooperation levels are the same, cooperation in port access for competition requires a higher level of cooperation than regional welfare until regional welfare requires complete cooperation. In contrast, in the case of terminal management in Figure 4.6 (b), cooperation for regional welfare requires a higher level of cooperation than the competition at any hinterland transport cost. The required cooperation effects differ according to the motivation for each transport cost.

Figure 4.6 also shows the loss of each objective function for each motivation (i.e., welfare in the regional market (Ir) and increment of cargo throughput in the competitive market (Ic)) when incorrect optimum cooperation is constructed, e.g., when cooperation for regional welfare realizes the optimum cooperation level in competition without considering the difference in motivations. The loss changes depending on the hinterland transport costs. The loss is larger in the area where the gap between the optimum cooperation levels between motivations is larger: middle transport cost in the case of port access and low transport cost in the case of terminal management.



(a) (b)

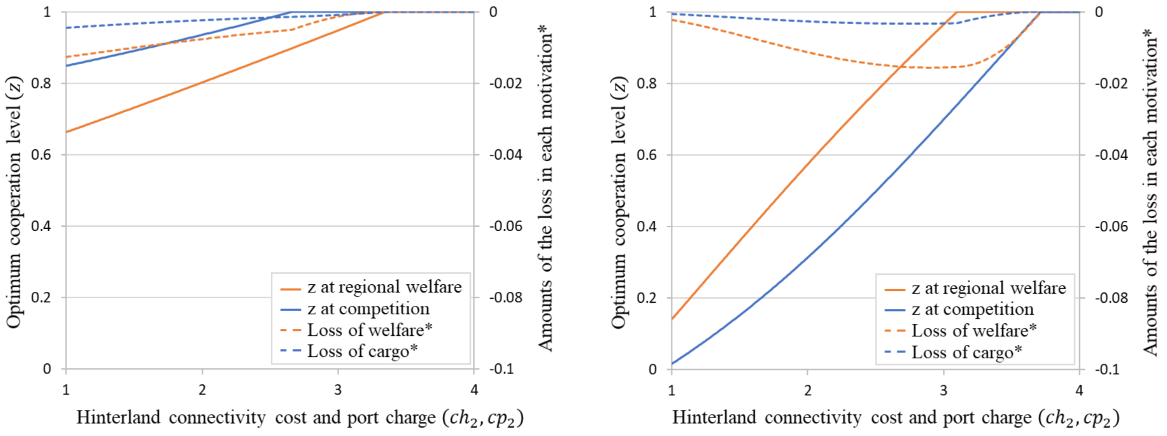
Figure 4.6 Accessibility scenario (a) Port access (b) Terminal management

* Loss of welfare in the regional market and cargo in the competitive market when incorrect optimum cooperative strategies are constructed

(b) Competitiveness scenario

Figure 4.7 shows the optimum cooperation level for each type and motivation and the loss in incorrect cooperative motivations in the competitiveness scenario. This scenario simulates the impact of cooperation at different port competitiveness levels on the optimum level. Although the gradients are different, both types require higher cooperation levels as port costs increase, and they finally require complete cooperation, similar to the accessibility scenario. This finding indicates that different cooperative strategies should be developed to improve port competitiveness. Highly competitive ports with low costs should compete with each other. Ports with low competitiveness and high port costs must cooperate.

Regarding the difference in motivations, cooperation for competition requires a higher cooperation level than cooperation for competition in port access, as shown in Figure 4.7 (a) Cooperation for regional welfare requires a higher cooperation level of cooperation than cooperation for competition in terminal management, as shown in Figure 4.7 (b). The loss is larger in areas where there is a higher gap in the optimum cooperation levels between motivations, similar to the accessibility scenario. Specifically, the gaps are large in lower-competitiveness ports in cooperation with port access and in higher-competitiveness ports in cooperation with terminal management.



(a) (b)

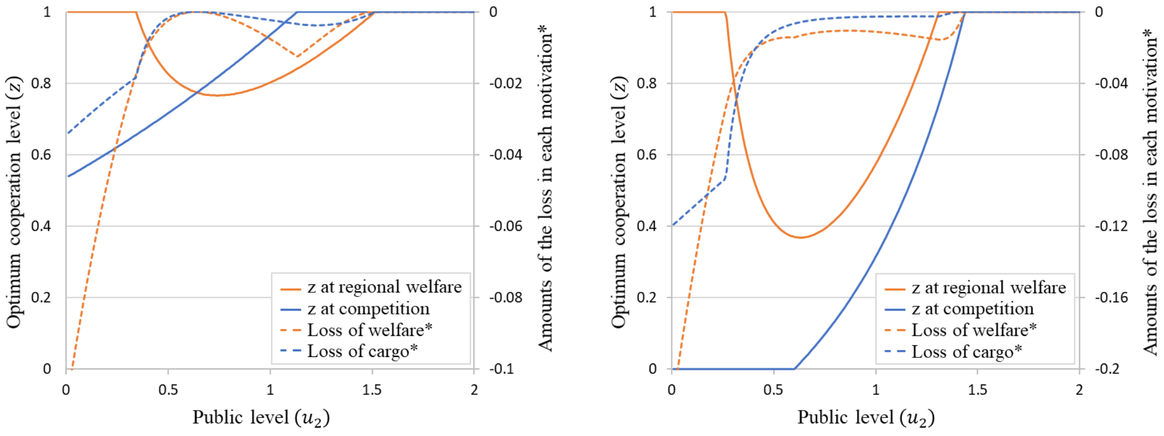
Figure 4.7 Competitiveness scenario (a) Port access (b) Terminal management

* Loss of welfare and cargo with wrong optimum cooperation level, same as in Figure 4.6

(c) Public scenario

Figure 4.8 shows the optimum cooperation level for each type and motivation and the loss in incorrect cooperative motivations in the case of the public scenario. This scenario simulates the impact of cooperation with different degrees of port publicness on the optimal cooperation level. Cooperation for competition in both types requires higher cooperation levels as the public level increases. Port competition is an effective strategy to compete with a third competitor in a private port. On the other hand, cooperation for regional welfare in both types is a convex function of the cooperation level. Port cooperation is an effective strategy for highly private or public ports.

As for the difference in motivations, the magnitude of relationships of cooperation level between different motivations changes depending on the motivation and public level. In cooperation with port access (Figure 4.8 (a)), cooperation for regional welfare requires a higher level of cooperation in private ports and a lower level in public ports. In cooperation with terminal management, as shown in Figure 4.8 (b), regional welfare requires a higher level of cooperation than competition. The loss is larger in low public level areas with a larger gap in the optimum cooperation level because regional welfare requires perfect cooperation while competition does not. This loss is larger than in other scenarios, such as accessibility and competitiveness.



(a) (b)

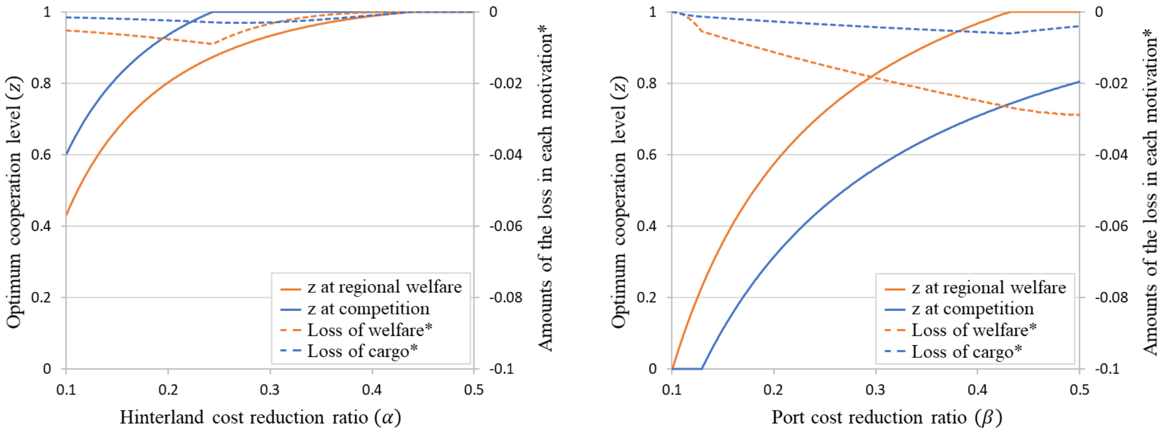
Figure 4.8 Public scenario (a) Port access (b) Terminal management

* Loss of welfare and cargo in the wrong optimum cooperation level, same as in Figure 4.6

(d) Reduction ratio scenario

Figure 4.9 shows the optimum cooperation level for each type and motivation and the loss in incorrect cooperative motivations in the case of the reduction ratio scenario. This scenario simulates the impact of cooperation with different cost reductions as the cooperation effect. Although the gradients are different, both types of cooperation require a higher level as the reduction ratio increases. Except for cooperation for competition in terminal management, they require complete cooperation, as in the accessibility, competitiveness, and reduction ratio scenarios. Different cooperation schemes should be constructed based on cost reduction through cooperation. Ports in which a high cost reduction is expected should construct cooperative schemes. Ports in which a low-cost reduction is expected should create competition.

As for the difference in motivations, the magnitude relationships of the optimum cooperation level did not change. They are the same as in the competitiveness scenario: competition requires a higher cooperation level in port access, and regional welfare requires a higher level of cooperation in terminal management. The loss is larger in areas where the gap between the cooperation levels for regional welfare and competition is higher, similar to the other scenarios. The loss is as small as in the accessibility and competitiveness scenario and is smaller than in the public scenario.



(a) (b)

Figure 4.9 Reduction scenario (a) Port access (b) Terminal management

* Loss of welfare and cargo in wrong optimum cooperation level, same as in Figure 4.6

4.2.2.3 Summary and discussion

Table 4.4 presents the optimum cooperation levels for scenario, cooperation type, and motivation. Low and high values were selected for each scenario. Based on the results reported in the previous section and Table 4.4, we can summarize the following two findings regarding the difference of cooperation level between cooperation for regional welfare and competition.

First, the optimal cooperation levels for regional welfare and competition differ. In many situations, cooperation for port access requires a higher level of cooperation for competition than for regional welfare, as shown in Table 4.4. This is because cooperation for competition requires higher improvement to achieve high competitiveness. However, there are several cases in which cooperation in port access requires a lower level of cooperation for competition than for regional welfare, specifically, low transport costs and low public levels. Additionally, cooperation in terminal management requires a lower level of cooperation for competition than for regional welfare, in any case. The required cooperation effects change depending on the type of cooperation and the situation.

Second, the loss of each objective function in each motivation (i.e., welfare in the regional market (Ir) and increment of cargo throughput in the competitive market (Ic)) changes depending on the port situation. The loss is larger in areas with a relatively large gap in the optimum cooperation levels between motivations. In particular, the loss is larger in low public-level areas because regional welfare requires perfect cooperation, whereas competition does not. The amount of loss in other situations was not as large as that at the low public level.

We obtain the following policy implications from the above summary. Ports with different motivations should make a different cooperative strategy to realize effective port cooperation. For example, ports cooperating in terminal management should make a more cooperative strategy for regional welfare than cooperation for competition. The relationships of optimum cooperative strategies in different motivations change depending on the port situation and cooperation type. Especially, private ports have the largest gap between optimum cooperative strategies in different cooperative motivations.

Table 4.4 Optimum cooperation level for different scenarios, cooperation types, and motivations

Cooperation type		Port access		Terminal management	
Cooperation Motivation		Regional welfare	Competition	Regional welfare	Competition
Base case		0.803	0.936	0.575	0.315
Accessibility scenario	Low transport cost $cs = 1.00, cv = 2.00$	0.659	0.520	0.445	0.073
	High transport cost $cs = 2.50, cv = 3.50$	0.896	1	0.699	0.478
Competitiveness scenario	Low port cost $cp_2 = 1.00, ch_2 = 1.00$	0.644	0.850	0.142	0.017
	High port cost $cp_2 = 2.50, ch_2 = 2.50$	0.875	0.984	0.777	0.499
Public scenario	Low public level $u_2 = 0.30$	1	0.640	0.827	0
	High public level $u_2 = 1.20$	0.865	1	0.824	0.564
Reduction ratio scenario	Low reduction ratio $ua, ub = 0.150$	0.673	0.818	0.357	0.113
	High reduction ratio $ua, ub = 0.300$	0.933	1	0.827	0.563

*Of the two motivations, the underlined values indicate the one with the higher value

4.3 Optimum cooperation types for different cooperative motivations

This chapter derives the optimum cooperation type in a specific port situation by considering three cooperation issues that include motivation, level, and effect.

4.3.1 Methodology

We develop the bi-level optimization model between shippers and ports. The model is applied to a Case study of the cooperation or competition between Kobe and Osaka and the competition between Kobe and Busan.

4.3.1.1 Model setting

The case study in this chapter focuses on Japanese cargo to/from North American and Southeast Asian ports. This is because the International Container Strategic Port (ICSP) policy that planned the cooperation between Kobe and Osaka ports focuses on North American cargo, as mentioned in Chapter 3 (MLIT, 2016). Additionally, the amount of Southeast Asian cargo is largest in Kobe and Osaka ports. We analyze the hinterland and transshipment cargo between Japan and those two regions. The hinterland cargo is the import/export cargo in the inland destination/origin. The transshipment cargo is moved cargo from one vessel to another in the port.

Figure 4.10 shows the amount of two types of cargo originating or destined for Japan in Busan, Kobe, and Osaka. Figure 4.10 indicates that hinterland cargo is competitive in Kobe and Osaka. It is worth noting that Busan port does not have any Japanese hinterland cargo because Busan port does not locate in Japan. We divide the hinterland into three areas; Kobe advantageous, competitive, and Osaka advantageous. Kobe advantageous and Osaka advantageous area indicates that Kobe and Osaka have a larger cargo due to the advantage of closer distance, respectively. Wan et al. (2018) emphasize the importance of considering these captive markets in each port. The competitive area is where Kobe and Osaka compete and have a similar amount of cargo. Table 4.5 shows the amount of hinterland cargo in each area. Kobe port has a larger amount of North American cargo than Osaka in all three hinterland areas. As for the Southeast Asian cargo, Kobe has a larger amount in Kobe advantageous and a lower amount in Osaka advantageous areas than Osaka and competes with Osaka in a competitive area. The specific area of the three hinterland areas is shown in Appendix F.

Figure 4.10 also indicates that the Japanese transshipment cargo in Kobe and Osaka ports is lower than in Busan port. Especially, the amount of Osaka is relatively low compared to Kobe and Busan ports. This result indicates the higher importance of Busan port in the Japanese cargo network, which is consistent with the results in Chapter 3. However, if we focus on five large local ports in west Japan (Hakata, Kitakyushu, Hiroshima, Mizushima, and Tokuyama ports) where Kobe and Osaka ports locate, the amount of transshipment cargo in Busan, Kobe and Osaka are 473256, 171593, and 9161 ton. The comparison indicates the transshipment cargo of west Japanese local ports is competitive in Busan and Kobe ports. Thus, we choose two ports (Kitakyushu and Hiroshima ports) in western Japanese ports for the transshipment cargo. The Southeast Asian and North American cargo of the two ports is competitive in Kobe and Busan ports. It is worth noting that as the number of ports in the model increase, the computation time increase. Table 4.5 shows the amount of transshipment cargo.

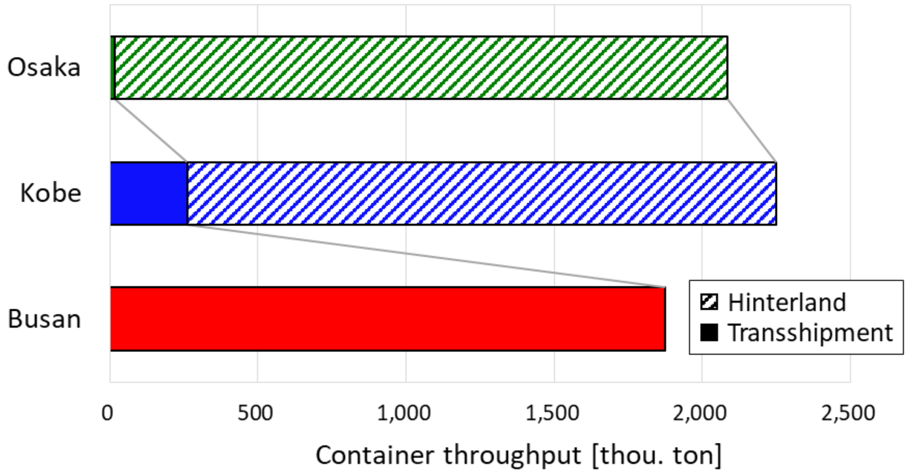


Figure 4.10 Amount of cargo originating or destined to Japan in Busan, Kobe and Osaka in 2018

Source: Nationwide Flow Survey of Export-Import Container Cargos in 2018 in Japan (MLIT, 2019)

Table 4.5 Amount of hinterland and transshipment cargo in Osaka, Kobe and Busan

		Hinterland			Transshipment	
		Kobe adv.*	Competitive	Osaka adv.*	Kitakyushu	Hiroshima
North America	Osaka	5,835	2,944	18,913	0	8657
	Kobe	110,607	20,249	67,858	10,256	12,251
	Busan				14,828	23,477
Southeast Asia	Osaka	22,592	66,300	285,715	130	0
	Kobe	276,936	47,320	54,610	5,318	90,379
	Busan				22,838	24,625

Source: Nationwide Flow Survey of Export-Import Container Cargos in 2018 in Japan (MLIT, 2019)

*adv.: advantageous

Figure 4.11 illustrates the flow of containers in the simulations. We categorized three hinterland areas as a set of the hinterland (Rh) and two transshipment as a set of transshipment in the formulation (Rt) in the formulation. This study assumes that export and import cargo are bundled as demand between Japan and North America or Southeast Asia. The sum of two sets about hinterland and transshipment is categorized as the set of origin/destination R $(R = Rh \cup Rt)$. We also categorized North America and Southeast Asia as the destination/origin S. Three ports that include Busan, Kobe, and Osaka ports are categorized as set of port *I*. The component of set R, I and S are expressed as *r, i* and s in the formulation, respectively. The model detects each flow between hinterland *r* and port *i* (fh_{ri}), transshipment *r* and port *i* (ft_{ri}) and port *i* and area s (fm_{is}) and container thorough put in port *i* (x_{is}).

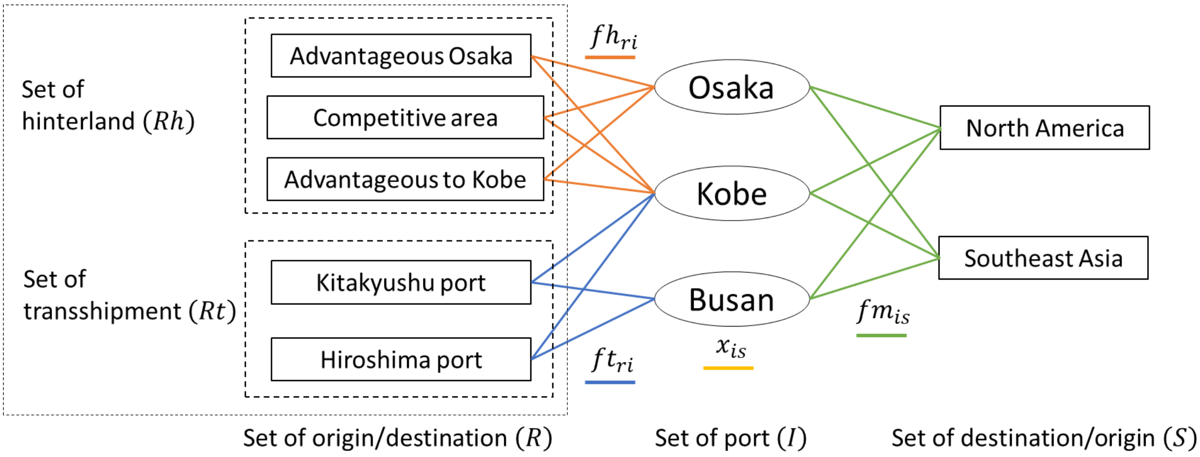


Figure 4.11 Overview of cargo flow in the simulation of Chapter 4.3

4.3.1.2 Model development

We developed the bi-level optimization model between shippers and ports with port competition to implement the case study. Figure 4.12 illustrate the overview of the bi-level optimization model. In the upper level, Busan, Kobe, and Osaka ports decide each port charge with competing or cooperating to maximize their own port benefit. We derive the Nash equilibrium of optimal charge for each port. In the lower level, a transshipment or hinterland cargo shipper determines the port to use as stochastic user equilibrium. The notations of the model are as follows.

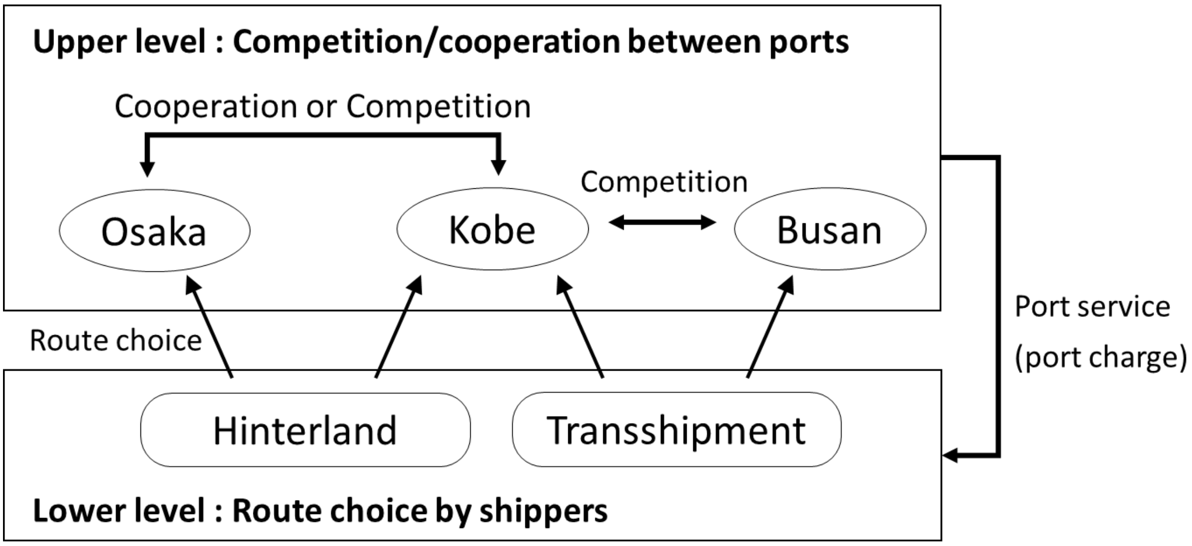


Figure 4.12 Overview of bi-level optimization model in Chapter 4.3

Notation

Rh	Set of origin(destination) in hinterland
Rt	Set of origin(destination) in transshipment cargo
R	Set of origin(destination) region
I	Set of ports
S	Set of destination(origin) region

Qh_{rs}	Total container throughput between regions *r* and *s* in hinterland
Qt_{rs}	Total container throughput between regions *r* and *s* in transshipment
qh_i^{rs}	Container throughput between regions *r* and *s* via *i* in hinterland
qt_i^{rs}	Container throughput between regions *r* and *s* via *i* in transshipment
oh_{ri}	Amount of other region cargo between region *r* and port *i* in hinterland
ot_{ri}	Amount of other region cargo between region *r* and port *i* in transshipment
om_{is}	Amount of other region cargo between port *i* and region *s* in maritime transport
ox_{is}	Amount of other region cargo between port *i* and region *s* in port
fh_{ri}	Cargo flow between region *r* and port *i* in hinterland
ft_{ri}	Cargo flow between region *r* and port *i* in transshipment
fm_{is}	Cargo flow between port *i* and region *s* in maritime transport
θh	Scale parameter in hinterland
θt	Scale parameter in transshipment
GCh_i^{rs}	Generalized transport cost between regions *r* and *s* via port *i* in hinterland
GCt_i^{rs}	Generalized transport cost between regions *r* and *s* via port *i* in transshipment
Gh_{ri}	Generalized hinterland cost between region *r* and port *i*
Gt_{ri}	Generalized transshipment cost between region *r* and port *i*
Gp_{is}	Generalized port cost between port *i* and regions *s*
Gm_{is}	Generalized maritime cost between port *i* and region *s*
x_{is}	Amount of cargo at port *i* from(to) region *s*
w_{is}	Port charge at port *i* from(to) region *s*
kh_r	Capacity of hinterland region *r*
kp_{is}	Assigned capacity to cargo from(to) region *s* at port *i*
ch_{ri}	Monetary hinterland cost between region *r* and port *i*
ct_{ri}	Monetary transshipment cost between region *r* and port *i*
cm_{is}	Monetary maritime cost between port *i* and region *s*
th_{ri}	Shipping time between region *r* and port *i* in hinterland
tt_{ri}	Shipping time between region *r* and port *i* in transshipment
tp_{is}	Waiting time at port in transport between port *i* and region *s*
tm_{is}	Shipping time between port *i* and region *s* in maritime transport
vt	Value of time of cargo
$\alpha h,\ \beta h$	Cost parameters related to cargo aggregation in hinterland
γh	Cost parameters related to the value of time in hinterland
$\alpha t, \beta t$	Cost parameters related to cargo aggregation in transshipment
γt	Cost parameters related to the value of time in transshipment
$\alpha p, \beta p$	Cost parameters related to cargo aggregation in port
γp	Cost parameters related to the value of time in port
$\alpha m, \beta m$	Cost parameters related to cargo aggregation in maritime transport
γm	Cost parameters related to the value of time in maritime transport

Π_i	Benefit of port *i*
π_{is}	Benefit of port *i* to region *s*
cq_i	Marginal operation cost in port *i*
ck_i	Terminal maintenance cost in port *i*
φo	Cost parameters for assigning influence on other region cargo to port benefit
φu	Cost parameters for assigning user surplus to port benefit
φp	Weight parameter of the cooperative port in regional benefit
z_{ij}	Cooperation level between ports *i* and *j*
Vc_s	Objective value of cooperation for competition in region *s*
Vr_s	Objective value of regional welfare in region *s*
Bc_{is}	Amount of transshipment at port *i* from(to) region *s*
Br_{is}	Regional benefit at port *i* from(to) region *s*
Uh_i^{rs}	User surplus at port *i* between regions *r* and *s*
Pr_i^{rs}	Profit of port *i* by the cargo between regions *r* and *s*
$qh_{i,obs}^{rs}$	Observed container throughput between regions *r* and *s* via *i* in hinterland
$GCh_{i,obs}^{rs}$	Observed generalized transport cost between regions *r* and *s* via port *i* in hinterland

The novelty of this model is the analysis of the equilibrium between the shipper and the port. A previous study, for example, analyzed the feasibility of port cooperation between Hong Kong and Shenzhen ports with the port choice only from the shipper's perspective (Wang et al., 2012). However, Talley and Ng (2021) indicated that the port choice with one perspective could result in unrealistic results and emphasized the importance of considering of equilibrium of shipper and port in cargo port choice. The developed model in this study realizes the analysis of equilibrium between shipper and port in the port cooperation, which is the contribution of this model to the previous studies.

(a) Upper level: Competition/cooperation between ports

In the upper level, each port decides on port charge in each region (w_{is}) to maximize its own port benefits (Π_i). Equation 4.8 indicates the port benefit. We calculate the port benefit as a sum of the own port benefit (π_{is}) and the benefit of partner ports in the case of cooperation. The degree taking into the consideration benefit of partner ports is controlled by cooperation level (z_{ij}). The cooperation level takes a value from 0 to 1. If the cooperation level is zero or one, then the two ports are completely competitive or completely cooperative same, as in Chapter 4.2.

$$\max_{w_{is}} \Pi_i = \sum_{s \in S} \pi_{is} + \sum_{j \in I} z_{ij} \cdot \Pi_j$$

subject to

$$w_{is} > 0, \ \ i \in I, s \in S \tag{4.8}$$

We formulate the port benefit as the sum of operating profit, capacity cost, user surplus, and influence on other region cargo, as shown in Equation 4.9. The port benefit depends on the result of the lower level that calculates container throughput (x_{is}). Operating profit is the cargo revenue, calculated by port charge and container throughput, minus operating costs such as labor cost in port (cq_i). Capacity cost is to maintain and invest terminal in the port. We calculate the cost with maintenance cost (ck_i) and square of port capacity because Song et al. (2018) and Dong et al. (2018) mentioned that the capacity cost is convexly increasing with port capacity. User surplus (Uh_i^{rs}) is an impact on shippers with the change of port strategy, such as port cooperation. We calculate the user surplus with observed generalized cost $\left(GCh_{i,obs}^{rs}\right)$ and container throughput $\left(qh_{i,obs}^{rs}\right)$ based on the rule of half (Winker 2015). The user surplus weight is balanced with parameter (φu) like Cui and Notteboom (2018) and Takebayashi and Hanaoka (2021). Another region cargo indicates the influence on the cargo not focused on this simulation, such as Europe or Africa with the change of port strategy. We calculate the value with the amount of cargo (ox_{is}), port charge, and balancing parameter (φo).

$$\pi_{is} = (w_{is} - cq_i)x_{is} - ck_i \cdot {kp_{is}}^2 + \varphi u \cdot Uh_i^{rs} - \varphi o \cdot w_{is} \cdot ox_{is}$$
$$Uh_i^{rs} = 0.5\left(GCh_{i,obs}^{rs} - GCh_i^{rs}\right)\left(qh_i^{rs} + qh_{i,obs}^{rs}\right) \tag{4.9}$$

(b) Lower level: Route choice by shippers

In the lower level, the shipper decides on each port to transport based on stochastic user equilibrium, which is defined as the state when shippers believe they cannot reduce their generalized cost by unilaterally changing routes. Previous studies such as Bell (1995) and Zhou et al. (2005) expressed the stochastic user equilibrium assignment as a logit-type model. Equation 4.10 indicates the calculation of the logit-type model in hinterland cargo. We calculate the container throughput of each port in hinterland (qh_i^{rs}) based on the probability to be decided by adjusting the weight of generalized cost with the parameter (θt) and total container throughput in transshipment $\left(Qt_{rs}\right)$. Generalized cost in the hinterland (GCh_i^{rs}) consists of generalized hinterland cost (Gh_{ri}), which is the cost to transport between the hinterland and Kobe or Osaka ports, generalized port cost (Gp_{is}) and generalized maritime cost (Gm_{is}). Figure 4.13 (a) illustrates the generalized transport cost in the hinterland.

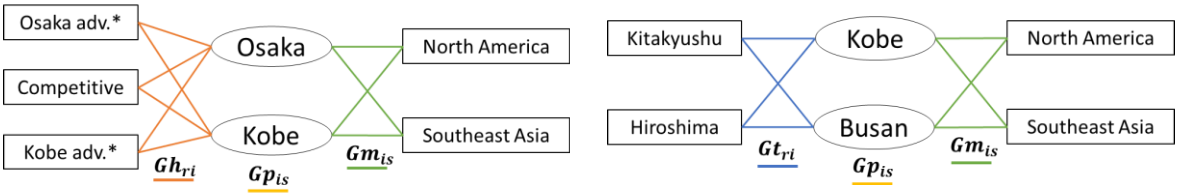
$$qh_i^{rs} = Qh_{rs}\frac{-\theta h \cdot GCh_i^{rs}}{\sum exp\left(-\theta h \cdot GCh_i^{rs}\right)}$$
$$GCh_i^{rs} = Gh_{ri} + Gp_{is} + Gm_{is} \tag{4.10}$$

Equation 4.11 indicates the calculation of the logit-type model in transshipment. We calculate the container throughput of each port in transshipment (qt_i^{rs}) based on the probability to be decided by adjusting the weight of generalized cost with the parameter (θt) and total container throughput in transshipment (Qt_{rs}). Generalized transport cost in transshipment (GCt_i^{rs}) consists of generalized transshipment cost (Gt_{ri}), the cost to transport between Japanese local port and Kobe or Busan ports, generalized port cost (Gp_{is}), and generalized maritime cost. Figure 4.13 (b) illustrates the generalized transport cost in transshipment.

$$qt_i^{rs} = Qt_{rs}\frac{-\theta t \cdot GCt_i^{rs}}{\sum exp\left(-\theta t \cdot GCt_i^{rs}\right)}$$
$$GCt_i^{rs} = Gt_{ri} + Gp_{is} + Gm_{is} \tag{4.11}$$

Equation 4.12 detect the amount of each flow between hinterland r and port i (fh_{ri}), transshipment r and port i (ft_{ri}) and port i and region s (fm_{is}) and container thorough put in port i (x_{is}) in Figure 4.11. Each flow is a sum of hinterland or transshipment cargo and cargo other than North America and Southeast Asia $(oh_{ri},\ ot_{ri},\ om_{is},\ ox_{is})$.

$$
\begin{aligned}
&fh_{ri} = oh_{ri} + \sum_{s\in S} qh_i^{rs} \\
&ft_{ri} = ot_{ri} + \sum_{s\in S} qt_i^{rs} \\
&fm_{is} = om_{is} + \sum_{r\in Rt} qt_i^{rs} + \sum_{r\in Rh} qh_i^{rs} \\
&x_{is} = ox_{is} + \sum_{r\in Rt} qt_i^{rs} + \sum_{r\in Rh} qh_i^{rs}
\end{aligned}
\tag{4.12}
$$



(a) (b)

Figure 4.13 Composition of generalized cost (a) hinterland $(\boldsymbol{GCh_i^{rs}})$ (b) transshipment $(\boldsymbol{GCt_i^{rs}})$

*adv.: advantageous

Equations 4.13 indicate the generalized costs in each factor. The generalized cost is composed of monetary cost $(ch_{ri},\ w_{is},\ ct_{ri},\ cm_{is})$ and time cost $(th_{ri},\ tp_{is},\ tt_{ri},\ tm_{is})$.

$$
\begin{aligned}
&Gh_{ri} = ch_{ri} + \gamma h \cdot vt \cdot \left(th_{ri} + \alpha h \cdot \left(\frac{fh_{ri}}{kh_r}\right)^{\beta h} \right) \\
&Gp_{is} = w_{is} + \gamma p \cdot vt \cdot \left(tp_{is} + \alpha p \cdot \left(\frac{x_{is}}{kp_{is}}\right)^{\beta p} \right) \\
&Gt_{ri} = ct_{ri} \cdot \alpha t \cdot (ft_{ri})^{\beta t} + \gamma t \cdot vt \cdot tt_{ri} \\
&Gm_{is} = cm_{is} \cdot \alpha m \cdot (fm_{is})^{\beta m} + \gamma m \cdot vt \cdot tm_{is}
\end{aligned}
\tag{4.13}
$$

The impacts of flow on the generalized cost are different. Specifically, generalized hinterland and port costs are the cost in the land. The time cost of land increases with the increase of flow. Marginal land cost increase with the increase of flow due to congestion (Takebayashi and Hanaoka, 2021 and Shibasaki and Kawasaki et al., 2019). Thus, we set the time costs in the two generalized costs with the capacity of hinterland and port and parameters $(\alpha h, \beta h, \alpha p, \beta p)$ to satisfy conditions in Equation 4.14. The weights of the monetary costs in the two generalized are balanced with parameters $(\gamma t, \gamma m)$.

$$\frac{\partial Gh_{ri}}{\partial fh_{ri}} > 0 \; and \; \frac{\partial^2 Gh_{ri}}{\partial {fh_{ri}}^2} > 0$$

$$\frac{\partial Gp_{is}}{\partial x_{is}} > 0 \; and \; \frac{\partial^2 Gp_{is}}{\partial {x_{is}}^2} > 0 \tag{4.14}$$

Generalized transshipment and maritime costs are the cost of shipping with a vessel. The monetary cost of shipping with a vessel decreases with the flow increase. The marginal cost of shipping by vessel increases with the flow due to the economy of density (Takebayashi and Hanaoka, 2021 and Tagawa et al., 2021). Thus, we set the monetary costs in the two generalized costs with parameters $(\alpha t, \beta t, \alpha m, \beta m)$ to satisfy conditions in Equation 4.15 as the economy of density. Weights of the time costs in the two generalized are balanced with parameters $(\gamma t, \gamma m)$.

$$\frac{\partial Gt_{ri}}{\partial ft_{ri}} < 0 \; and \; \frac{\partial^2 Gt_{ri}}{\partial {ft_{ri}}^2} > 0$$

$$\frac{\partial Gm_{is}}{\partial fm_{is}} < 0 \; and \; \frac{\partial^2 Gm_{is}}{\partial {fm_{is}}^2} > 0 \tag{4.15}$$

4.3.1.3 Solution algorithm

The proposed model requires three equilibriums; the equilibrium between ports as cooperation or competition (Equilibrium 1), the equilibrium between port and shipper as bi-level optimization (Equilibrium 2), and the equilibrium between shippers as stochastic user equilibrium (Equilibrium 3). The computation difficulty in obtaining an exact solution for the model is discussed in Zhou et al. (2005) and Takebayashi and Hanaoka (2021). We propose the following heuristic algorithm.

[Algorithm]

```
Step 0. Set the initial iteration number for the overall loop $n = 1$ and initial port charge solution $\hat{\boldsymbol{\omega}}(\mathbf{0})$
Step 1. Solve the bi-level optimization model between port i and shippers
  Step 1.0. Set the initial iteration number for the bi-level loop $j = 1$ and previous iteration solution as the initial port charge $\omega_{is}(j) = \hat{\omega}_{is}(n-1) \;\; \forall i, \forall s$
  Step 1.1. Solve stochastic user equilibrium (SUE) problem with partial linearization method
    Step 1.1.0. Set the initial iteration number for the SUE loop $k = 1$ and initial flow $\boldsymbol{y}(\mathbf{0})$
    Step 1.1.1. Choose the route and obtain auxiliary flow $\hat{\boldsymbol{y}}(\boldsymbol{k})$ in the given port charges $\omega_{is}(j)$ and previous flow $\boldsymbol{y}(\boldsymbol{k}-\mathbf{1})$
    Step 1.1.2. Solve the SUE problem with partial linearization and obtain flow $\boldsymbol{y}(\boldsymbol{k})$
    Step 1.1.3. If $\sum(\boldsymbol{y}(\boldsymbol{k}) - \boldsymbol{y}(\boldsymbol{k}-\mathbf{1}))^2 \le \varepsilon,\; \boldsymbol{x}(\boldsymbol{j}) = \boldsymbol{y}(\boldsymbol{k})$ and go to Step 1.2. Otherwise $k = k + 1$ and return to Step.1.1.1.
  Step 1.2. Solve the maximization of the benefit of port $i$ in the given flow $\boldsymbol{x}(\boldsymbol{j})$ and obtain port charges $\omega_{is}(j)$
  Step 1.3. If $\sum(\omega_{is}(j) - \omega_{is}(j-1))^2 \le \varepsilon,\; \hat{\omega}_{is}(n) = \omega_{is}(j) \;\; \forall s$ and go to Step 2. Otherwise $j =$
```

```
    $j + 1$ and return to Step.1.1
Step 2. If all ports are explored, go to step 3. Otherwise, update the port number $i = i + 1$ and go to Step 1.
Step 3. If $\sum(\widehat{\boldsymbol{\omega}}(\boldsymbol{n}) - \widehat{\boldsymbol{\omega}}(\boldsymbol{n-1}))^2 \le \varepsilon$, terminate. Otherwise, update the overall loop $n = n + 1$ and go to Step 1.
```

We develop the algorithm with the nest structure that Equilibrium 1 includes Equilibrium 2 and Equilibrium 2 includes Equilibrium 3. Specifically, each port needs to achieve the equilibrium between the port and shipper in Equilibrium 2 before ports achieve equilibrium in Equilibrium 1. Each shipper needs to achieve the equilibrium between shippers in Equilibrium 3 before the shipper and port achieve equilibrium in Equilibrium 2. The algorithm solves Equilibrium 3 with the partial linearization method. We can obtain the flow $\boldsymbol{y}(\boldsymbol{k})$ to minimize the partial linearized SUE problem with a golden-section search in the partial linearization method (JSCE, 1998). The algorithm solves Equilibrium 1 and 2 with the method of successive average based on Zhou et al. (2005) and Takebayashi and Hanaoka (2021). The algorithm repeats the calculation until equilibrium solutions are obtained. The algorithm was coded in MATLAB and run on an Intel® Core™ i7-9700 processor with 16 GB of RAM. The computation time of an experiment is about one day. The procedure of the algorithm is illustrated in Appendix G.

4.3.1.4 Evaluation of each motivation

The difference in motivations, which include cooperation for regional welfare and competition, is the focused market, as discussed in Chapter 4.2. Specifically, regional welfare focuses on the market share with the cooperative port, and competition focuses on the market share with the competitive port. Thus, the evaluation of each motivation is based on different values reflecting the difference of the focused market. Both values focused on the change ratio from non-cooperation in Kobe port because Kobe port cooperates with Osaka port and competes with Busan port. The objective value of regional welfare (Vr_s) considers the benefit of hinterland cargo shared with Kobe and Osaka ports, and the objective value of competition (Vc_s) considers the amount of transshipment cargo shared with Kobe and Busan ports. We separately calculate the values in each region competition (s), that is, each scenario four results; values for regional welfare in North America and East Asia and values for competition in North America and East Asia.

Equations (4.16) indicate the objective value of regional welfare as the function of regional benefit (Br_{is}). We analyze the regional benefit of Kobe port. The regional benefit is composed of the profit of the port (Pr_i^{rs}) and user surplus (Uh_i^{rs}) of Kobe port and Osaka as the cooperative port. As the cooperation level increase, the weight of Osaka port in the regional welfare increase. The weights of values of the cooperative port are adjusted with the parameter (φp) to represent the weight of Osaka port is less than Kobe to the regional welfare of Kobe port.

$$Vr_s = \frac{Br_{(i=Kobe)s}}{{Br_{(i=Kobe)s}}^{z=0}}$$

$$Br_{is} = \sum_{r\in Rh} \left(Pr_i^{rs} + Uh_i^{rs} + \sum_{j\in I} \varphi p \cdot z_{ij}\left(Pr_j^{rs} + Uh_j^{rs}\right) \right)$$

$$Pr_i^{rs} = (w_{is} - cq_i)qh_i^{rs} - \frac{qh_i^{rs}}{x_{is}} \cdot ck_i \cdot {kp_{is}}^2 \tag{4.16}$$

Equations (4.17) indicate the objective value of competition as the function of the amount of transshipment cargo (Bc_{is}). The value focuses on Kobe port to analyze the competition with Busan port in transshipment cargo.

$$Vc_s = \frac{Bc_{(i=Kobe)s}}{{Bc_{(i=Kobe)s}}^{z=0}}$$

$$Bc_{is} = \sum_{r\in Rt} qt_i^{rs} \tag{4.17}$$

4.3.1.5 Input values and scenario analysis

Table 4.6 shows input values. We prepare the values based on actual maritime transport. For example, monetary transshipment cost is a sum of fuel, capital, and operation costs. The fuel cost is based on the fuel consumption per day, which is the third power function of navigation speed (Wang and Meng, 2012). The capital cost is the cost of acquiring or financing the vessel. Operation cost includes the cost of crew, maintenance, and insurance (Hsu and Hsieh, 2005). Shipping time of Kobe, advantageous, competitive, and Osaka advantageous areas in the hinterland are calculated based on the distance between Kobe or Osaka ports and Himeji city, Hanshin Inland Container Depot Shiga Minakuchi, and Sakai city, respectively. Shipping time of North America and Southeast Asia in transshipment is calculated based on the distance between Busan, Kobe, or Osaka ports and Los Angeles and Laem Chabang ports, respectively. The breakdown of each input value is shown in Appendix H.

Table 4.6 Input values of Chapter 4.3

			Busan	Kobe	Osaka	Unit
ct_{ri}	Monetary transshipment cost	Kitakyushu	57.5	115.6	-	[USD/TEU]
		Hiroshima	96.5	146.2	-	
tt_{ri}	Shipping time in transshipment	Kitakyushu	3.05	4.96	-	[Day]
		Hiroshima	4.14	3.74	-	
ch_{ri}	Monetary hinterland cost	Kobe Adv.	-	372	522	[USD/TEU]
		Comp	-	678	618	
		Osaka Adv.	-	264	114	
th_{ri}	Shipping time in hinterland	Kobe Adv.	-	3.07	3.9	[Hour]
		Comp	-	4.77	4.43	
		Osaka Adv.	-	2.47	1.63	
kh_r	Capacity of hinterland	Kobe Adv.		1,000,000		[TEU/year]
		Comp		1,000,000		
		Osaka Adv.		1,000,000		
tp_{is}	Waiting time at port	North America	2.09	3.7	4.75	[Day]
		Southeast Asia	2.04	2.11	2.16	
kp_{is}	Assigned capacity to the cargo	North America	300,628	38,138	5,179	[TEU]
		Southeast Asia	169,927	92,212	51,543	
cm_{is}	Monetary maritime cost	North America	169.7	185.8	186.2	[USD/TEU]
		Southeast Asia	82.52	117.6	117.6	
tm_{is}	Shipping time in maritime transport	North America	13.1	14.3	14.7	[Day]
		Southeast Asia	6.73	8.40	8.41	
cq_i	Operation cost in port		61.08	69.04	70.86	[USD/TEU]
ck_i	Terminal maintenance cost		$4.05 \cdot 10^{-5}$	$2.44 \cdot 10^{-4}$	$1.59 \cdot 10^{-4}$	[USD/TEU^2]
vt	Value of time			400		[USD/day]

Sources: Each port HP, OC (2018), Shibasaki and Kawasaki (2021), Ishii et al. (2013), Shibasaki et al. (2017)

USD: United States dollar, TEU: Twenty-foot Equivalent Unit

Table 4.7 indicates the parameters to adjust the weight of each value in their decision. We detect the values to minimize the difference between observed and estimated values and set the same numerical value for the values with similar meanings. Specifically, the parameters related to the hinterland $(\alpha h, \beta h, \gamma h)$ and port $(\alpha p, \beta p, \gamma p)$ have the same values because they both indicate the cost of the land. As for the parameters related to maritime and transshipment, although they both indicate cost in shipping with a vessel and two sets of parameters $(\alpha t, \alpha m)$ and $(\beta t, \beta m)$ are the same, the parameter for the value of time in transshipment (γt) is lower than the value of time in maritime transport (γm). The parameters satisfy the conditions in Equations 4.14 and 4.15. We set the values based on the assumption that the marginal cost in time reduction is different because the transshipment requires lower navigation time by shorter navigation distance than maritime transport.

Table 4.7 Parameter to adjust the weight of each values

Hinterland	For cargo aggregation	αh	2.00
	For cargo aggregation	βh	1.50
	For value of time	γh	0.60
Transshipment	For cargo aggregation	αt	0.50
	For cargo aggregation	βt	-0.10
	For value of time	γt	0.50
Port	For cargo aggregation	αp	2.00
	For cargo aggregation	βp	1.50
	For value of time	γp	0.60
Maritime	For cargo aggregation	αm	0.50
	For cargo aggregation	βm	-0.10
	For value of time	γm	0.15
Scale parameter in hinterland		θh	-0.0057
Scale parameter in transshipment		θt	-0.010
Weight of user surplus in port benefit		φu	0.30
Weight of influence on other region cargo to port benefit		φo	0.0070
Weight of the cooperative port in regional benefit		φp	0.50

Figure 4.14 illustrates the comparison between the observed and estimated values of cargo. Although some estimated values are lower than observed values, trends fit the observed and estimated values. Additionally, we change the different input values. The errors in results are sufficiently small, indicating the uniqueness of the solutions. Therefore, we adopted the proposed model that includes input values and estimated parameters as the base case.

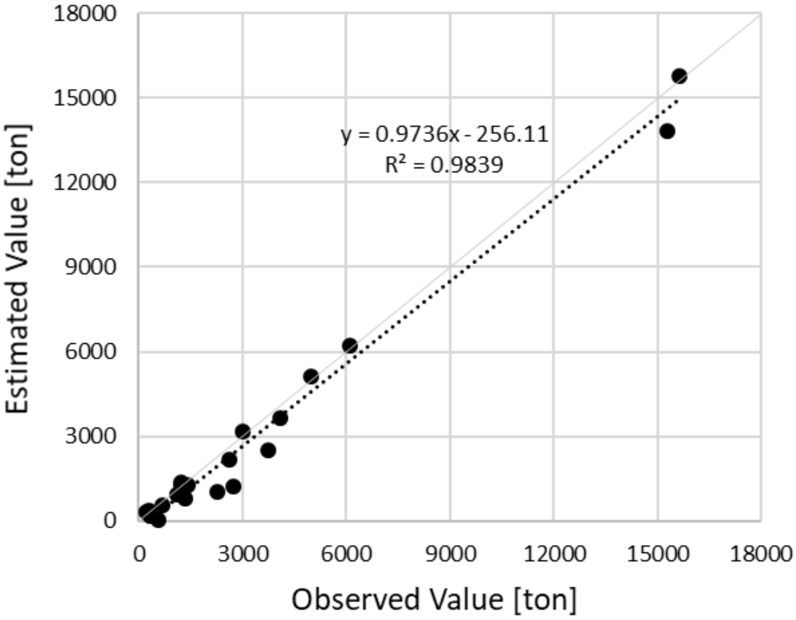


Figure 4.14 Reproducibility of cargo (solid line: forty-five-degree line, dot line: approximate line from the observed data)

We prepare six scenarios to analyze cooperation types. The first scenario is the shipping cost scenario, called scenario 1. Scenario 1 focuses on reducing shipping costs in transshipment and hinterland as a cooperation effect, categorized as port access in cooperation type. The second scenario is the shipping time scenario, called scenario 2. Scenario 2 focuses on reducing shipping time in transshipment and hinterland, categorized as port access in cooperation type. The third scenario is the port operation scenario, called scenario 3. Scenario 3 focuses on reducing waiting time and operation costs in port, categorized as terminal management in cooperation type. The fourth scenario is the port capacity scenario, called scenario 4. Scenario 4 focuses on the capacity expansion and reduction of capacity cost, categorized as terminal management in the cooperation type. The fifth scenario is all shipping scenario, called scenario 5. Scenario 5 focuses on reducing shipping costs and time in transshipment and hinterland; that is, scenario 5 focuses on improving all factors in port access as cooperation type. The final scenario is all port scenario, called scenario 6. Scenario 6 focuses on the reduction of waiting time and operation cost in port and the capacity expansion and reduction of capacity cost of port; that is, scenario 6 focuses on improving all factors in terminal management as cooperation type. Table 4.8 indicates the focused values in each scenario. The reduction ratio (increase ratio in capacity expansion) depends on the cooperation level as the cooperation effect. If ports realize complete cooperation $\left(z_{ij} = 1\right)$ in scenarios 1 to 4, focused values are reduced by 20%. If ports realize complete cooperation $\left(z_{ij} = 1\right)$ in scenarios 5 and 6, focused values are reduced by 10%. We assumed that scenarios 5 and 6 focus on more factors than scenarios 1 to 4, and the reduction ratio in each factor becomes lower. As for the cooperation level, we compare the result of five values $\left(z_{ij} = 0, 0.25, 0.50, 0.75, 1.00\right)$.

Table 4.8 Focus of each scenario in Chapter 4.3

		Scenario					
		1	2	3	4	5	6
ct_{ri}	Monetary transshipment cost	✓				✓	
tt_{ri}	Shipping time in transshipment		✓			✓	
ch_{ri}	Monetary hinterland cost	✓				✓	
th_{ri}	Shipping time in hinterland		✓			✓	
tp_{is}	Waiting time at port			✓			✓
cq_i	Operation cost in port			✓			✓
ck_i	Terminal (capacity) cost				✓		✓
kp_{is}	Capacity at port*				✓		✓
Reduction ratio of each factor		$0.2 \times z_{ij}$				$0.1 \times z_{ij}$	
Cooperation type**		A	A	M	M	A	M

* Capacity increase by cooperation

**A: Port access, M: Terminal management in Table 4.1

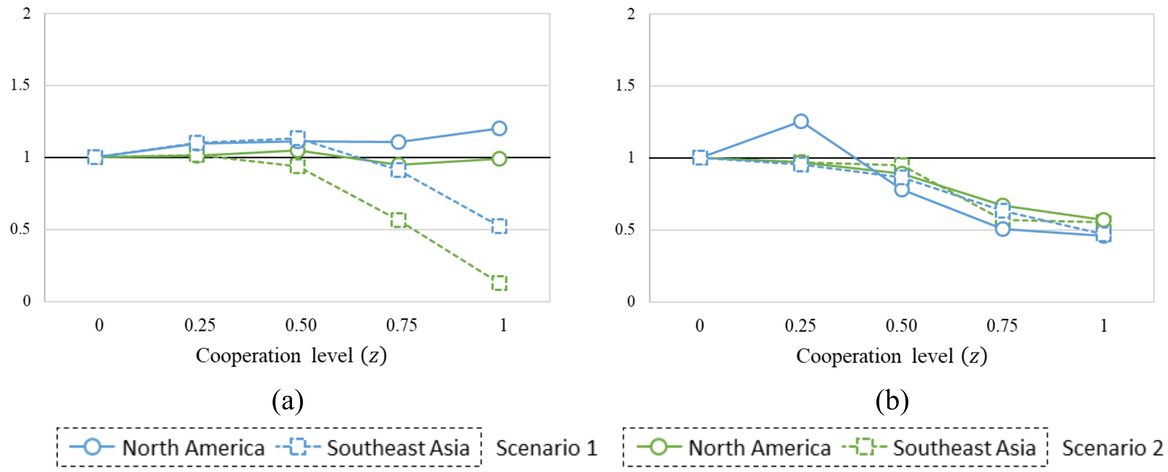
4.3.2 Results and Discussion

4.3.2.1 Scenario analysis

(a) Scenario 1 (Shipping cost scenario) and scenario 2(Shipping time scenario)

Figure 4.15 indicates the objective values in scenario 1, which focuses on the reduction of shipping cost in transshipment and hinterland, and scenario 2, which focuses on the reduction of shipping time in transshipment and hinterland. Table 4.9 shows the change of the generalized cost of the shipper from the base in scenarios 1 and 2. As shown in Figure 4.15 (a), the regional welfare of both scenarios in Southeast Asia decreases from the base in high cooperation level. On the other hand, the regional welfare of scenario 1 in North America increases at all cooperation levels and the regional welfare of scenario 2 does not drastically change. This result indicates the optimum cooperation change depending on the focusing market. The difference is due to the different impacts of cooperation effect in each region. This model considers the two cooperation effects as cost reduction by efficiency improvement and higher market power as higher port charge. The cost reduction causes the increase of user surplus with the decrease of the generalized cost. The higher port charge decreases user surplus with the increase of the generalized cost. As shown in Table 4.9, the generalized cost of scenario 1 in North America decreases from the base and the generalized cost of both scenarios in Southeast Asia increase from the base. Although the generalized costs of scenario 2 in both regions increase from the base, the increase in North America is lower than in Southeast Asia. The effects of cost reduction and higher port charge in North America are larger and lower than in Southeast Asia, respectively. The decrease in the amount of cargo to the increase of port charge in North America is more significant than in Southeast Asia due to the difference in the amount of captive cargo. The elasticity of the amount of cargo to port charge results in the different cooperation effects in North America and Southeast Asia.

As for the values in cooperation for competition in Figure 4.15 (b), the values of 0.25 cooperation level in scenario 1 about North American cargo is larger than the base, and the other cases are less than the base. As shown in Table 4.9, only the generalized transshipment cost in scenario 1 about North American cargo is lower than the base. The impact of cost reduction is larger than a higher port charge as cooperation effect in the case. This result indicates that the optimum cooperation change depending on the focusing market, similar to cooperation for regional welfare. The number of effective scenarios and cooperation levels for the competition is smaller than cooperation for regional welfare.



(a) (b)

Figure 4.15 Objective values in scenarios 1 and 2 (a) Regional welfare ($\boldsymbol{Vr_s}$) (b) Competition ($\boldsymbol{Vc_s}$)

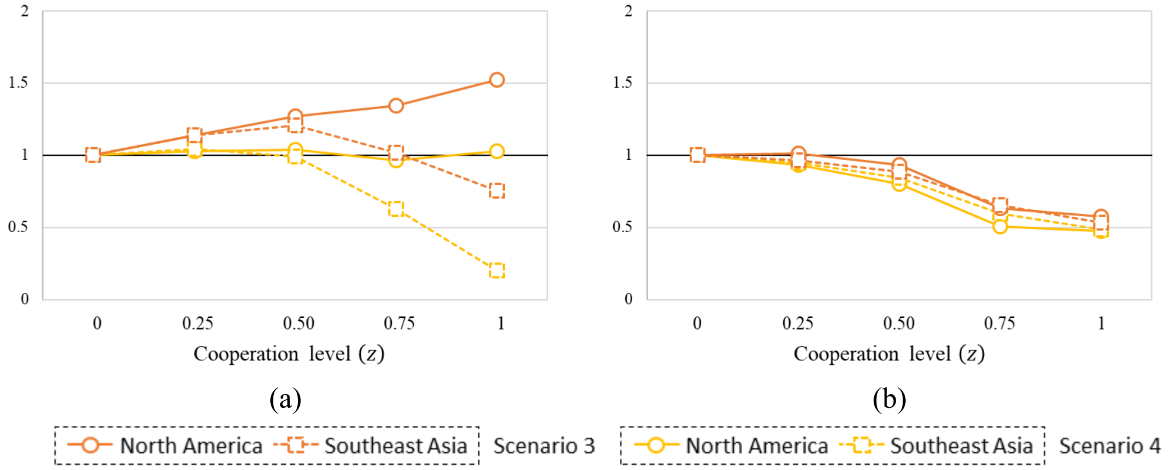
Table 4.9 Change of generalized cost from the base in scenarios 1 and 2 $\left(\boldsymbol{i = Kobe, z_{ij} = 0.25}\right)$

	Region (s)	Scenario 1	Scenario 2
Hinterland: GCh_i^{rs} ($r = competitive$)	North America	-162.5	51.7
	Southeast Asia	24.4	72.8
Transshipment: GCt_i^{rs} ($r = Hiroshima$)	North America	-130.1	16.7
	Southeast Asia	56.8	37.8

(b) Scenario 3 (Port operation scenario) and scenario 4 (Port capacity scenario)

Figure 4.16 indicates the objective values in scenario 3, which focuses on reducing waiting time and operation cost in port, and scenario 4, which focuses on the capacity expansion and reduction of capacity cost. Table 4.10 shows the change of the generalized cost of the shipper from the base in scenarios 3 and 4. As shown in Figure 4.16 (a), the regional welfare of both scenarios in Southeast Asia decreases from the base in high cooperation level similar to scenarios 1 and 2. On the other hand, the regional welfare of scenario 3 in North America increases at all cooperation levels and the regional welfare of scenario 4 does not drastically change. Especially the increase in the welfare of scenario 3 in North America is larger than in other scenarios. The welfares in both regions of 0.50 cooperation level are higher than the base, which shows the cooperation type is effective for the regional welfare. The differences of regions and scenarios are due to the different impacts of cooperation effect in each region, the same as in scenarios 1 and 2.

As for the values in cooperation for competition in Figure 4.16 (b), the values of 0.25 cooperation level in Scenario 3 about North American cargo is slightly larger than the base. As shown in Table 4.10, the generalized cost of the case is lower than the base. The impact of higher port charges is slightly larger than cost reduction as a cooperation effect. The value of the other cases is less than the base. This result indicates that the optimum cooperation changes depending on the focusing market, similar to Scenarios 1 and 2.



(a)

(b)

Figure 4.16 Objective values in scenarios 3 and 4 (a) Regional welfare ($\boldsymbol{Vr_s}$) (b) Competition ($\boldsymbol{Vc_s}$)

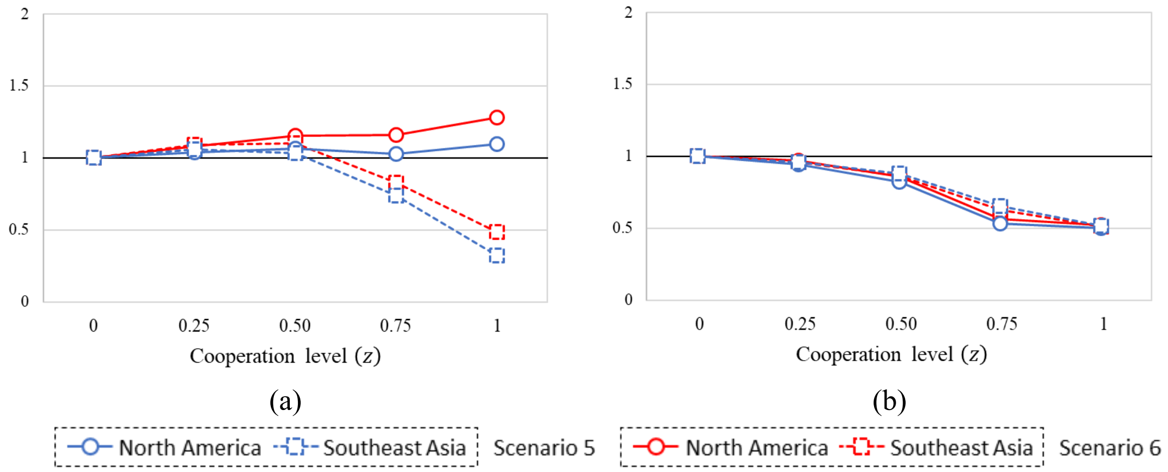
Table 4.10 Change of generalized cost from the base in scenarios 3 and 4 $\left(\boldsymbol{i = Kobe, z_{ij} = 0.25}\right)$

	Region (s)	Scenario 3	Scenario 4
Hinterland: GCh_i^{rs} ($r = competitive$)	North America	-6.0	42.1
	Southeast Asia	42.5	63.8
Transshipment: GCt_i^{rs} ($r = Hiroshima$)	North America	-6.0	42.2
	Southeast Asia	42.6	63.9

(c) Scenario 5 (All shipping scenario) and Scenario 6 (All port scenario)

Figure 4.17 indicates the objective values in scenario 5, which focus on improving all factor in port access, and scenario 6, which focus on improving all factor in terminal management. Table 4.11 shows the change in the generalized cost of the shipper from the base in scenarios 5 and 6. As shown in Figure 4.17 (a), the regional welfare of both scenarios in Southeast Asia decreases from the base in high cooperation level similar to the other scenarios. Table 4.11 indicates that the generalized costs of the shipper in scenarios 5 and 6 are higher than the base. The impact of higher port charges is larger than cost reduction as the cooperation effect in all regions.

As for the values in cooperation for competition in Figure 4.17 (b), Values in all scenarios and cooperation levels are less than the base. As shown in Table 4.11, the generalized costs increase from the base the same as the hinterland. The impact of higher port charges is larger than cost reduction as cooperation effect in all scenarios. This result indicates that cooperation focusing on many factors with a lower reduction ratio is ineffective for the competition and the importance of concentrated investment in cooperation.



(a) (b)

Figure 4.17 Objective values in scenario 5 and 6 (a) Regional welfare ($\boldsymbol{Vr_s}$) (b) Competition ($\boldsymbol{Vc_s}$)

Table 4.11 Generalized cost in scenario 5 and 6 $\left(\boldsymbol{i = Kobe, z_{ij} = 0.25}\right)$

	Region (s)	Scenario 5	Scenario 6
Hinterland: GCh_i^{rs}	North America	32.9	18.3
($r = competitive$)	Southeast Asia	48.6	52.8
Transshipment: GCt_i^{rs}	North America	31.7	18.4
($r = Hiroshima$)	Southeast Asia	47.3	52.9

4.3.2.2 Summary

Table 4.12 presents whether the objective values of cooperation for regional welfare and competition in each cooperation type and level are larger than the base. Based on the results reported in the previous section and Table 4.12, we can summarize the following two findings regarding the difference in cooperation types between cooperation for regional welfare and competition.

First, cooperation contributes to improving regional welfare regarding Southeast Asian cargo in all scenarios and low cooperation levels. However, cooperation does not contribute to improving competition about Southeast Asian cargo in all scenarios and cooperation levels. On the other hand, cooperation contributes to improvement in the competition about North American cargo in two cases; 0.25 cooperation level in Scenario 1 and 3. The difference is due to the different impacts of cooperation effect by different elasticity of the amount of cargo to port charge in each region. The effects of cost reduction and higher port charge in North America are larger and lower than in Southeast Asia, respectively. Those results indicate the importance of considering the focus market to build a cooperative strategy for both motivations.

Second, Scenarios 5 and 6, which focus on many factors with a lower reduction ratio, do not contribute to the improvement in competition. Scenarios 2 and 4 also do not contribute to the improvement in competition. The two cases where cooperation contributes to improvement in the competition are 0.25 cooperation level in Scenario 1 and 3. The high cooperation level does not contribute to the improvement in competition. Effective cooperative strategy for competition in Kobe and Osaka ports can only be realized under limited conditions.

Table 4.12 Comparison of base and each objective value in each cooperation scenario and level

		Cooperation level (z_{ij})			
		0.25	0.5	0.75	1
Scenario 1	North America	R/C	R	R	R
(Shipping cost)	Southeast Asia	R	R		
Scenario 2	North America	R	R		
(Shipping time)	Southeast Asia	R			
Scenario 3	North America	R/C	R	R	R
(Port operation)	Southeast Asia	R	R	R	
Scenario 4	North America	R	R		R
(Port capacity)	Southeast Asia	R			
Scenario 5	North America	R	R	R	R
(All shipping)	Southeast Asia	R	R		
Scenario 6	North America	R	R	R	R
(All port)	Southeast Asia	R	R		

* R: larger than base in cooperation for regional welfare
C: larger than base in cooperation for competition

4.4 Conclusion of Chapter 4

The objective of this chapter is to reveal the effectiveness of port cooperation for competition from the perspective of port and shipper as the demand in maritime transport. We set two objectives as Objective 4.1 and 4.2. Objective 4.1 is to reveal the optimum cooperation level for different cooperative motivations. Objective 4.2 is to reveal the optimum cooperation type for different cooperative motivations. The models in Chapters 4.2 and 4.3 are developed to achieve two objectives in Objective 4.1 and 4.2, respectively.

Chapter 4.2 examined the effectiveness of port cooperation for competition and the difference in optimum cooperation level for each motivation, which includes cooperation for regional welfare and competition, using a game-theoretical model. We analyzed three ports that compete or cooperate in a linear city, where shippers are uniformly distributed. The relationships with two cooperative ports and a third competitor enabled us to consider cooperation for competition differently from previous studies that considered cooperative relationships of two ports with game theory. We derived and compared the cooperative effort, which indicates the willingness to participate in port cooperation, by determining the optimum cooperation value to fit each motivation by considering the behavior of ports and shippers. Chapter 4.2 revealed the following three findings regarding port cooperation. First, port cooperation is an effective strategy for increasing cargo throughput with expanded boundaries in a competitive area. The cargo in a competitive area reaches a maximum when the port achieves a balance between cooperation and competition at the optimum cooperation level. Second, the optimum cooperation levels for regional welfare and competition are different because of the difference in cooperation effects in each motivation. Finally, the loss of welfare in the regional market and cargo in the competitive market with incorrect cooperation changes depending on the port situation. The loss is larger in areas with a larger gap in the optimum cooperation levels between motivations, especially in low public-level ports. These findings provide a benchmark to realize optimum cooperation for competition in various port situations and can assist policymakers in port management in realizing optimum port cooperation for competition as a methodological reference. Additionally, policymakers can apply knowledge about cooperation for regional welfare to cooperation for competition based on the differences in motivations obtained from this study.

Chapter 4.3 explores the optimum cooperation type for competition using a bi-level optimization model. In the upper level, Busan, Kobe, and Osaka ports decide each port charge with competing or cooperating to maximize their own port benefit. In the lower level, transshipment or hinterland cargo shippers determine the port to use as stochastic user equilibrium. We adapt the model to the cooperation or competition between Kobe and Osaka ports in hinterland cargo and competition between Busan and Kobe ports in transshipment cargo. We analyze six scenarios, including three scenarios about port access and three about terminal management. Chapter 4.3 revealed the following two findings regarding port cooperation. First, cooperation does not contribute to improving competition about Southeast Asian cargo in all scenarios and cooperation levels. On the other hand, cooperation contributes to improvement in the competition for North American cargo in some scenarios. Optimum cooperation types change depending on the focusing market. Second, cooperation contributes to improvement in the competition are low cooperation levels in shipping cost and port operation scenarios. Effective cooperative strategy for competition in Kobe and Osaka ports can only be realized under limited conditions. These findings provide a benchmark to realize optimum cooperation for competition in various port situations and can assist policymakers in port management in realizing optimum port cooperation for competition as a methodological reference. Additionally, policymakers can apply knowledge about cooperation for regional welfare to cooperation for competition based on the differences in motivations obtained from this study.

Chapter 4.2 developed a simplified model and considered the equilibrium between ports and shippers as a leader-and-follower relationship. Ports could make a more advantageous decision for ports than shippers. The model in Chapter 4.2 is not sensitive to changes in ports and is not suitable for considering more detailed conditions such as specific cooperation forms. The model in Chapter 4.3 is the model to solve the problem in Chapter 4.2. Chapter 4.3 developed the bi-level optimization model to be sensitive to port changes. However, the model in Chapter 4.3 could not analyze the various port situation that Chapter 4.2 analyzed due to computational costs. Chapters 4.2 and 4.3 are complementary to each other.

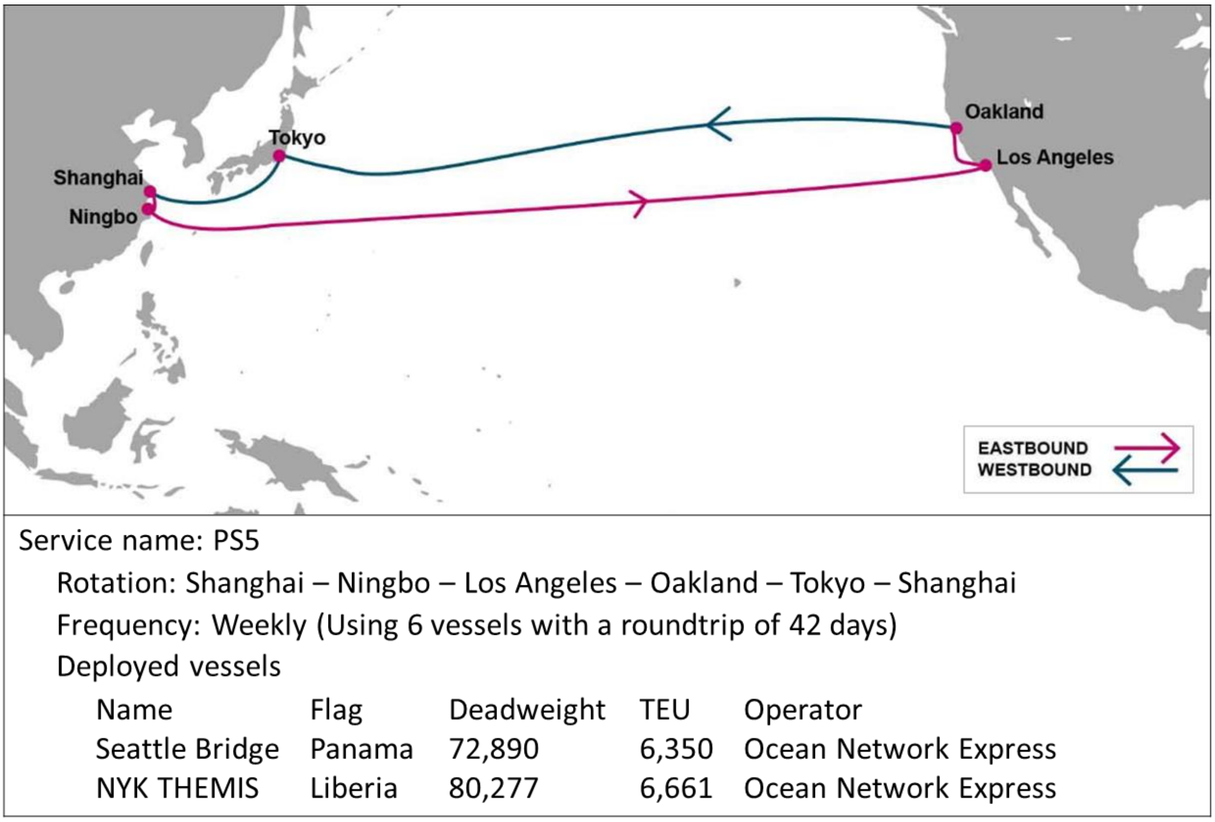
This chapter has several limitations in both Chapters 4.2 and 4.3. For example, both models analyze the cooperation or competition between three ports. Port compete with several nearby ports, not necessarily three, and the cooperative strategy might be changed. Second, both simulations simplify the distribution of shippers, such as a linear city or a limited number of shippers. The complex distribution of shippers might influence the optimum cooperative strategy. Third, the cooperation level z in Chapter 4.2 and z_{ij} in Chapter 4.3 is a benchmark to make a cooperative port strategy. The values do not indicate the practical and port strategies.

CHAPTER 5: Change of network designing of shipping line by port cooperation

5.1 Introduction

5.1.1 Framework of liner shipping network design problem (LSNDP)

This chapter reveals the effectiveness of port cooperation for competition from the perspective of ports and shipping lines as the supply in maritime transport, as mentioned in Chapter 1. Shipping line design multiple shipping services known as shipping networks. For example, Figure 5.1 shows an actual shipping service named PS5 operated by Ocean Network Express Pte. Ltd (ONE). Shipping services must decide which ports the service calls and which vessels are deployed in the service. We analyze the change in shipping services designed by the shipping line. We solve the liner shipping network design problem (LSNDP).



Service name: PS5

Rotation: Shanghai – Ningbo – Los Angeles – Oakland – Tokyo – Shanghai

Frequency: Weekly (Using 6 vessels with a roundtrip of 42 days)

Deployed vessels

Name	Flag	Deadweight	TEU	Operator
Seattle Bridge	Panama	72,890	6,350	Ocean Network Express
NYK THEMIS	Liberia	80,277	6,661	Ocean Network Express

Figure 5.1 Shipping service named PS5

(Source: ONE (2022) modified by authors)

LSNDP is defined as the task of designing a set of weekly services, assigning vessels to the services, and flowing the demand through the resulting network (Christiansen et al., 2020). The answer to the problem indicates the deployment of shipping services to ports around the world. Brouer et al. (2014) proved that the LSNDP is an NP-hard problem considering the traveling salesman problem and the set-covering problem. Christiansen et al. (2020) categorized the algorithms to solve LSNDP into four groups: MIP-based algorithm, Subset of routes, Two-stage algorithm, and Backbone flow. The MIP-based algorithm is formulated as a mixed integer programming model with two variables; variables to select arcs in service and variables to denote the flow on each arc (Wang and Meng, 2014 and Plum et al., 2014). The Subset of routes generates a shipping network by selecting a subset of sailing services from an initial pool of candidate services (Meng and Wang, 2011 and Balakrishnan and Karsten, 2017). The Two-stage algorithm first generates a set of services for the vessels and then solves the container flow problem. The feedback loop is created, iteratively improving the services and solving the container flow (Brouer et al., 2014, Monemi and Gelareh, 2017). Backbone flow is to reverse the order of the subproblems in the two-stage algorithm. The algorithm first flows the container and then constructs the shipping services to cover the flow (Krogsgaard et al., 2018). This study develops the Backbone flow algorithm because Christiansen et al. (2020) stated that the Backbone flow algorithm could solve large problem sizes.

5.1.2 Research framework

In this chapter, we analyze the impact of cooperation between Kobe and Osaka ports based on the LINER-LIB proposed by Brouer et al. (2014). LINER-LIB is a practical data set to compare algorithms for LSNDP. LINER-LIB contains data on ports, vessels, and a commodity set. Data on ports includes port call cost, cargo handling cost, and draft restrictions. Data on vessels includes distances between ports considering draft and canal traversal. Data on a commodity set includes quantities, revenue, and maximal transit time, intended to reflect the differentiated revenue associated with the current imbalance of world trade (Christiansen et al., 2020). Table 5.1 shows an overview of seven instances included in LINER-LIB. As the number of ports in instances increases, the calculation difficulty becomes larger. This study analyzes the WorldLarge instance to evaluate the change in competitiveness of cooperative ports in as many ports as possible. Appendix I shows the ports in WorldLarge.

Table 5.1 The seven instances included in LINER-LIB with the number of ports (Ports) and origin-destination pairs (Demands)

Instance name	Ports	Demands	Description
Baltic	12	22	Baltic sea with Bremerhaven as hub
WestAfrica	20	37	West Africa with Algeciras as hub to West African ports
Mediterranean	40	365	Mediterranean with Algeciras, Tangier, Gioia Taur as hubs
Pacific	45	722	Asia and West Coast of the United States of America
AsiaEurope	114	4000	Europe, Middle East and Far East regions
WorldSmall	47	1764	Main ports worldwide identified by Maersk Line
WorldLarge	201	9622	Majority of ports serviced directly by Maersk Line

Source: Brouer et al. (2014)

This chapter analyzes the cooperation between Kobe and Osaka ports, the same as Chapters 3 and 4.3. The original demand set in LINER-LIB is not suitable for analyzing the cooperation because the cargo demand of Osaka port is underestimated. Specifically, the amount of import and export cargo of Kobe ports are 1128 and 1090 FEU[1], respectively. Import and export cargo of Osaka ports are 58 and 17 FEU, respectively. Kobe port has about thirty times the cargo as much as Osaka port in LINER-LIB. However, the container throughputs of Kobe and Osaka ports were 2647066 and 2352250 TEU in 2020 (Llyod's list 2021). Kobe and Osaka ports are competitive. Therefore, we modify the demand of Osaka port to be competitive with Kobe port based on the Nationwide Flow Survey of Export-Import Container Cargos in 2018 in Japan (MLIT, 2019).

5.1.3 Objectives

The main objective of this chapter is to reveal the effectiveness of port cooperation for competition from the perspective of port and shipping lines as the supply in maritime transport. We set two objectives as follows;

Objective 5.1: To predict the liner shipping network design by the shipping line
Objective 5.2: To evaluate the change in the shipping network by port cooperation

Objective 5.1 is achieved by developing the backbone algorithm to solve LSNDP. Objective 5.2 is achieved by evaluating the shipping network with several cooperative scenarios about Kobe and Osaka ports. We implement network analysis in the shipping networks.

5.2 Methodology

5.2.1 Formulation of LSNDP

We formulate LSNDP to solve the two problems based on Krogsgaard et al. (2018); the profit maximization and flowing container problems. The profit maximization problem derives three variables; quantity of vessels deployed at shipping service a (q_a), binary variable, which takes 1 if shipping service *a* call on port *i* after *j*, otherwise 0 $\left(y_{ij}^{a}\right)$, and binary variable, which takes 1 if vessel type *w* is deployed on shipping service *a*, otherwise 0 (z_a^w). Note that vessel type is the class of vessel, including vessel information such as size and draft of vessels. The flowing container problem derives a variable; container flow from port *i* to *j* in service *a* about cargo between origin port *o* to destination port *d* $\left(x_{ij}^{a,od}\right)$. Figure 5.2 show an example of the result obtained from the decision variables.

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[1] FEU: Forty-foot Equivalent Unit, Roughly, 1 FEU = 2 TEU

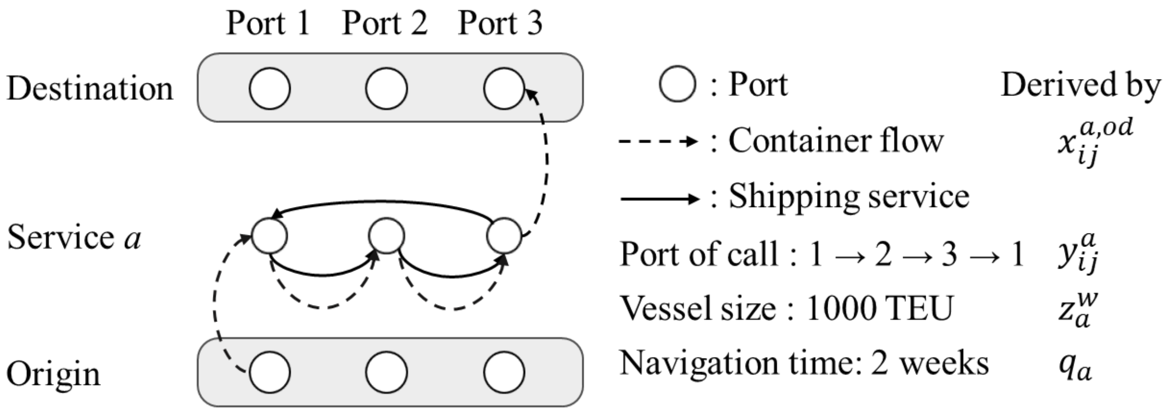


Figure 5.2 Example of the answer of LSNDP

Four assumptions are set in the model based on Brouer et al. (2014) and Krogsgaard et al. (2018); 1) the model do not analyze cabotage and embargo rules, which prevent specific from being transported on certain vessels, 2) the capacity at ports is practically unlimited, and port congestion does not occur, 3) the handling costs per container are constant regardless of the amounts of containers handled at the port, 4) all shipping services have a weekly operations. The number of fleets deploying the shipping service is the number of weeks of the service. The notations are as follows.

Notation

Ps	Profit of shipping line
X_{od}	Demand between origin port *o* and destination port *d*
$x_{ij}^{a,od}$	Container flow from port *i* to *j* in service *a* about cargo between origin port *o* to destination port *d*
bX_{ij}^{od}	Backbone flow from port *i* to *j* about cargo between origin port *o* to destination port *d*
bx_{ij}^{a}	Amount of backbone flow that can be transported in the link between ports *i* and *j in* service *a*
ox_{od}	Amount of omission cargo between origin port *o* to destination port *d*
$tx_{i}^{a,od}$	Amount of transshipment in service *a* at port *i* about cargo between origin port *o* to destination port *d*
y_{ij}^{a}	Binary variable, which takes 1 if shipping service *a* call on port *i* after *j*, otherwise 0
z_{a}^{w}	Binary variable, which takes 1 if vessel type *w* is deployed on shipping service *a*, otherwise 0
Z_{ij}^{w}	Binary value, which takes 1 if vessel type *w* can be deployed in ports *i* and *j*, otherwise 0
r_{od}	Revenue of cargo between origin port *o* and destination port *d*
c_{ij}^{a}	Link cost from port *i* to *j* in service *a*
$f_{ij}(x)$	Cost function of link between ports *i* and *j* depending on the flow *x* to calculate backbone flow
oc_{od}	Cost of omission cargo between origin port *o* to destination port *d*
gc_{od}	Penalty cost between origin port *o* to destination port *d*

lc_i	Loading/unloading cost in port *i*
tc_i	Transshipment cost in port *i*
s_w	Vessel size of vessel type *w*
v_a	Navigation speed of vessel at shipping service *a*
mv_w	Minimum navigation speed of vessel type *w*
Mv_w	Maximum navigation speed of vessel type *w*
q_a	Quantity of vessels deployed at shipping service *a*
mq_w	Minimum navigation time of vessel type *w*
Mq_w	Maximum navigation time of vessel type *w*
Q_w	Fleet quantity of vessel type *w*
h_{ij}	Distance between ports *i* and *j*
t_j^a	Stay at port *j* in service *a*
W	Set of vessel types
w	Vessel type
A	Set of shipping services
a	Shipping service
Ω	Set of origin and destination pairs
N	Set of ports
i, j, o, d	Port
λ_{ij}^a	Lagrange multiplier in the link from port *i* to *j* in service *a*
$\pi_{m,n}$	Weight of operator *m* in *n* th iteration
γ	Reaction factor to control the impact of the last iteration
$\delta_{m,n}$	Score of operator *m* in *n* th iteration
$\theta_{m,n}$	Number of times operator *m* in the iteration *n*
$\sigma_1, \sigma_2, \sigma_3$	Parameter of score

5.2.1.1 Profit maximization problem

We analyze the maximization of profit of the shipping line to solve LSNDP. The maximization problem is calculated based on container link flow $\left(x_{ij}^{a,od}\right)$ obtained from the flowing container problem and derives three variables; quantity of vessels (q_a), order of port call $\left(y_{ij}^a\right)$ and deployed vessel type for the service (z_a^w). The formulations are as follows;

$$\max Ps$$

$$\begin{aligned} Ps = {} & \sum_{(o,d)\in\Omega} (r_{od} - lc_o - lc_d)(X_{od} - ox_{od}) - \sum_{w\in W}\sum_{a\in A}\sum_{i\in N}\sum_{j\in N} s_w y_{ij}^a z_a^w c_{ij}^a \\ & - \sum_{a\in A}\sum_{i\in N}\sum_{(o,d)\in\Omega} tc_i \left| tx_i^{a,od} \right| \\ & - \sum_{(o,d)\in\Omega} gc_{od} \left(ox_{od} + \sum_{w\in W}\sum_{a\in A}\sum_{i\in N}\sum_{j\in N} y_{ij}^a z_a^w s_w - x_{ij}^{a,od} \right) \end{aligned} \tag{5.1}$$

s.t.)

$$q_a = \sum_{i\in N}\sum_{j\in N} \frac{y_{ij}^a \times h_{ij}}{v_a} + y_{ij}^a \times t_j^a \quad a \in A \tag{5.2}$$

$$\sum_{a\in A} z_a^w \times q_a \leq Q_w \quad w \in W \tag{5.3}$$

$$z_a^w \times mv_w \leq v_a \leq z_a^w \times Mv_w \quad a \in A, w \in W \tag{5.4}$$

$$z_a^w \times mq_w \leq q_a \leq z_a^w \times Mq_w \quad a \in A, w \in W \tag{5.5}$$

$$y_{ij}^a z_a^w \leq Z_{ij}^w \quad i,j \in N, a \in A, w \in W \tag{5.6}$$

$$\sum_{w\in W} z_a^w \leq 1 \quad a \in A \tag{5.7}$$

$$q_a \in \mathbb{Z}^+ \quad a \in A \tag{5.8}$$

$$y_{ij}^a \in \{0,1\} \quad i,j \in N, a \in A \tag{5.9}$$

$$z_a^w \in \{0,1\} \quad a \in A, w \in W \tag{5.10}$$

The equation (5.1) is to maximize the profit of the shipping line. The first term describes the revenue of a shipping line from cargo (r_{od}), loading/unloading cost (lc_i), container demand (X_{od}) and amount of omission cargo (ox_{od}). The omission cargo is defined as the containers not shipped on the network because the origin and destination are unconnected in the network. The second term indicates the cost of shipping service based on the link cost per container (c_{ij}^a), vessel size (s_w) and deployed vessel type to the link $(y_{ij}^a z_a^w)$. We calculate the link cost by fuel, capital, operation and port call costs in LINER-LIB. The third term is transshipment cost based on transshipment cost (tc_i) and transshipment volume $(tx_i^{a,od})$. We define that the positive value of $tx_i^{a,od}$ is unloading at the port to transshipment and the negative value is loading at the port to transshipment and thus, the absolute value is calculated. The fourth term is goodwill cost as the penalty for the omission cargo (ox_{od}) and the violating the link capacity $\left(\sum_{w\in W}\sum_{a\in A}\sum_{i\in N}\sum_{j\in N} y_{ij}^a z_a^w s_w - x_{ij}^{a,od}\right)$. We set the penalty cost per container (gc_{od}) to 1000 USD same as Krogsgaard et al. (2018).

Constraint (5.2) denotes the navigation time based on the distance (h_{ij}), navigation speed (v_a) and time in port (t_i^a). The number of vessels is the same as the navigation time as explained in the fourth assumption. We set the in port (t_i^a) to 24 hours same as Brouer et al. (2014) and Krogsgaard et al. (2018). Constraint (5.3) ensures that the number of deployed vessels does not exceed the number of fleets of each vessel type. Constraints (5.4) and (5.5) ensure navigation speed and navigation time are higher than minimum values (mv_w, mq_w) and lower than maximum values (Mv_w, Mq_w). Constraint (5.6) ensures whether the vessel type can be deployed on the service. The value Z_{ij}^w indicates whether the vessel type can deploy to ports *i* and *j* not violating the draft conditions. Constraint (5.7) defines that each shipping service deploys at most one vessel type. Constraint (5.8)-(5.10) defines the domain of decision variables.

5.2.1.2 Flowing container problem

We analyze the flowing container problem to solve LSNDP. The problem is calculated based on the network obtained from the profit maximization problem and derived container link flow $\left(x_{ij}^{a,od}\right)$. The formulations are as follows;

$$min \sum_{a\in A}\sum_{i\in N}\sum_{j\in N}\sum_{(o,d)\in\Omega} c_{ij}^a x_{ij}^{a,od} + \sum_{a\in A}\sum_{i\in N}\sum_{(o,d)\in\Omega} tc_i \left|tx_i^{a,od}\right| + \sum_{(o,d)\in\Omega} oc_{od} ox_{od} \tag{5.11}$$

s.t.)

$$\sum_{(o,d)\in\Omega} x_{ij}^{a,od} \le y_{ij}^a z_a^w s_w \quad i,j \in N,\ a \in A, w \in W \tag{5.12}$$

$$X_{od} = ox_{od} + \sum_{a\in A}\sum_{j\in N} x_{ij}^{a,od} \quad (o,d) \in \Omega, i = o \tag{5.13}$$

$$X_{od} = ox_{od} + \sum_{a\in A}\sum_{i\in N} x_{ij}^{a,od}\ (o,d) \in \Omega,\ j = d \tag{5.14}$$

$$\sum_{j\in N} x_{ij}^{a,od} - \sum_{j\in N} x_{ji}^{a,od} = tx_i^{a,od} \quad (o,d) \in \Omega,\ i \in N \setminus (o,d),\ a \in A \tag{5.15}$$

$$x_{ij}^{a,od} \in \mathbb{Z}^+ \cup \{0\} \quad (o,d) \in \Omega,\ i,j \in N \tag{5.16}$$

Equation (5.11) denotes the container flowing problem as the cost minimization of container flow. Krogsgaard et al. (2018) solved the container flow problem as a standard multi-commodity flow problem. The first term in Equation (5.11) indicates the link cost. The second term is the transshipment cost. The third term is goodwill cost as the penalty for the omission cargo. Constraint (5.12) ensures that each link flow is lower than the capacity of each link as the vessel size. Constraints (5.13) and (5.14) ensure the conservation of flow in the origin port and destination port, respectively. Constraint (5.15) ensures conservation of flow in a port other than origin and destination. Transshipment cargo in port is calculated as the difference between cargo incoming and outgoing to the port in each service. Constraint (5.16) defines the domain of decision variables.

5.2.2 Solution algorithm

The LSNDP is proved to be an NP-hard problem by Brouer et al. (2014), considering the traveling salesman problem and the set-covering problem. Therefore, we developed the backbone flow algorithm to obtain a heuristic solution based on Krogsgaard et al. (2018). The algorithm has two main parts; initial network designing and network optimization. It has five procedures; making backbone flow, making initial network, flowing container, network evaluation, and remaking network, as shown in Figure 5.3.

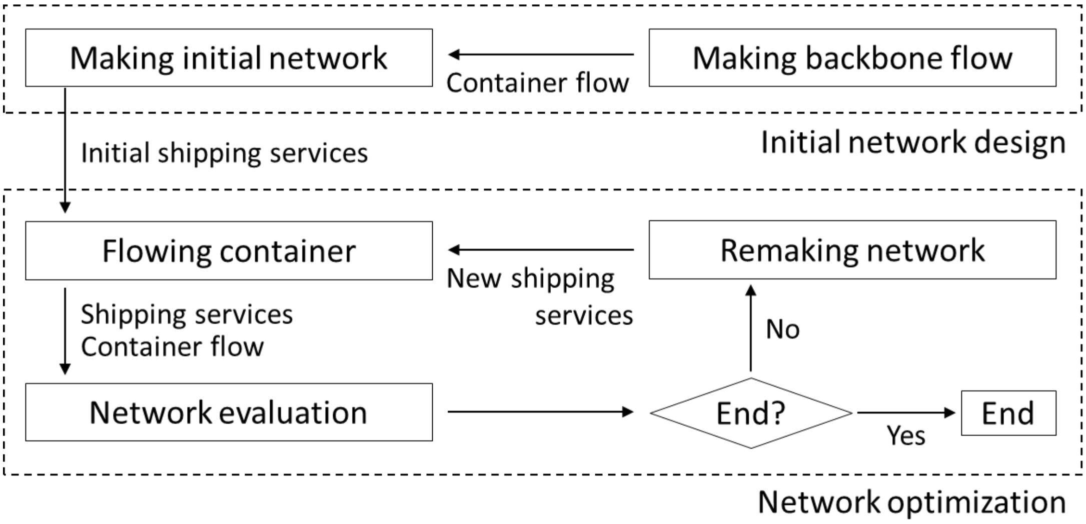


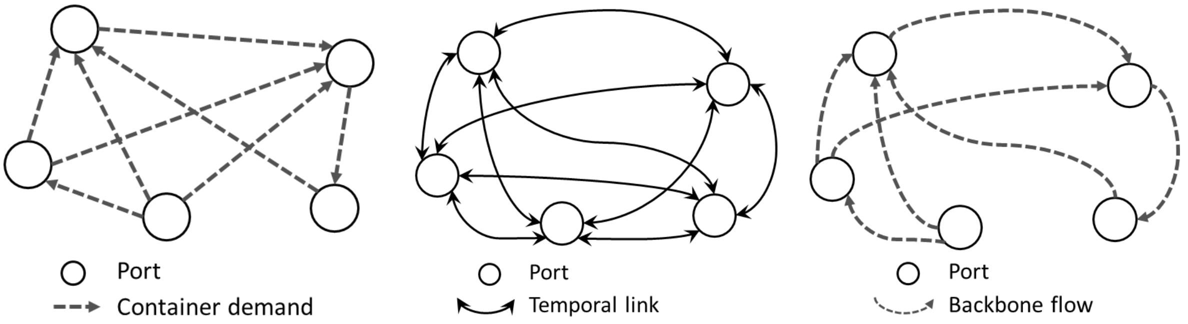
Figure 5.3 Overview of backbone algorithm

5.2.2.1 Initial network design

This part detects the initial solution to explore the optimum solution. Many previous algorithms for LSNDP use the existing network as an initial solution, which does not fully exploit the solution space and can lead to a biased solution. If we design a network from scratch by exploiting the vast solution space, we need to design based on flow demand and port conditions such as geographical location. Krogsgaard et al. (2018) developed the backbone algorithm to make the initial network not use the existing network. The idea is first to flow the container and then construct the network based on the flow. We name the first procedure making the backbone flow, and the second procedure making the initial network.

(a) Making backbone flow

This procedure is to flow the container, which is named backbone flow. Figure 5.4 illustrates the procedures of making backbone flow. There are only port and container flows and no network to flow the container at the beginning, as shown in Figure 5.4 (a). We prepare the artificial network to flow the container. This network is represented by a complete and directed network in which all ports connect with each other with a temporal link in Figure 5.4 (b). All ports are assumed to connect with direct services.



(a) (b) (c)

Figure 5.4 Procedures of making backbone flow: (a) only container demand, (b) artificial network and (c) backbone flow

We flow the demand in Figure 5.4 (a) to the artificial network in Figure 5.4 (b). The obtained flow, like in Figure 5.4 (c), is named backbone flow. We detect the backbone flow to solve the following multi-commodity flow problem.

$$\min \sum_{i \in N} \sum_{j \in N} f_{ij} \left(\sum_{(o,d) \in \Omega} bX_{ij}^{od} \right) \tag{5.17}$$

s.t.)

$$X_{od} = \sum_{j \in N} bX_{ij}^{a,od} \quad (o,d) \in \Omega, i = o \tag{5.18}$$

$$X_{od} = \sum_{i \in N} bX_{ij}^{a,od} \quad (o,d) \in \Omega, j = d \tag{5.19}$$

$$\sum_{j \in N} bX_{ij}^{od} - \sum_{j \in N} bX_{ji}^{od} = 0 \quad (o,d) \in \Omega, i \in N \setminus (o,d) \tag{5.20}$$

$$bX_{ij}^{od} \in \mathbb{Z}^{+} \cup \{0\} \quad (o,d) \in \Omega,\ i,j \in N \tag{5.21}$$

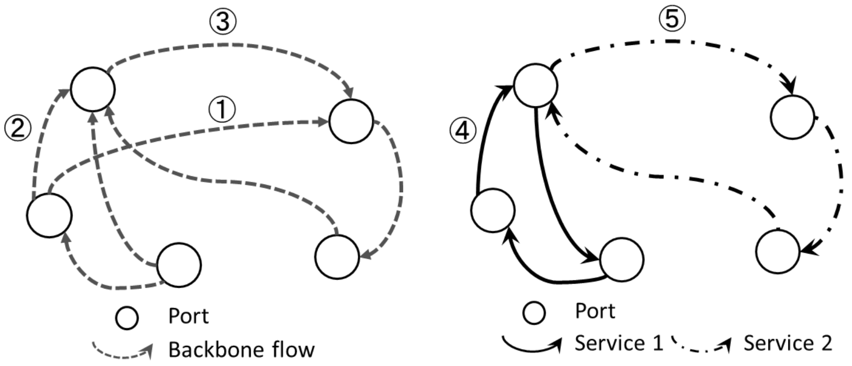
The objective function (5.17) indicates the cost minimization to flow all container. Ducruet and Notteboom (2012b) emphasized the importance of bundling container cargo to optimize ship utilization and benefit the most from scale economies in vessel size. The cost function $f(x)$ reflects the economy of scale for flowing more containers. We estimate the function by following two procedures. First, we calculate each link cost per container shipping by each vessel type having vessel size. Second, the points of link cost and vessel size are plotted, and we use curve fitting. An example of the cost function is shown in Appendix J.

Constraints (5.18) and (5.19) ensure the conservation of flow in the origin port and destination port, respectively. Constraint (5.20) ensures the conservation of flow in a port other than the origin and destination. Note that this problem does not include transshipment as considered in Constraint (5.15) because transshipment from one service to another service does not occur. Constraint (5.21) defines the domain of decision variables.

We solve the multi-commodity flow problem by detecting the cheapest paths using the Floyd-Warshall algorithm, a simple and widely used algorithm to compute the shortest paths between all pairs of nodes in a network (Hougardy, 2010). The link cost depends on the container flow of the link. Therefore, we repeatedly calculate the shortest path based on the flow in the last iteration until the solution achieves equilibrium.

(b) Making initial network

This procedure is to make the initial network based on backbone flow. Figure 5.5 illustrates the procedures for making the initial network. The objective is to cover the link with as much container flow as possible because we finally design a cost-effective shipping network. Note that we do not have to directly ship the container flow. For example, backbone flow 1 in Figure 5.5 (a) can be bundled into flows 2 and 3. The demand is shipped in service links 4 and 5 in Figure 5.5 (b).



(a) (b)

Figure 5.5 Procedures of making initial network (a) backbone flow and (b) initial network

We formulate the making initial network as following problem:

$$max \sum_{a \in A} \sum_{i \in N} \sum_{j \in N} bx_{ij}^{a} \tag{5.22}$$

s.t.)

$$\sum_{a \in A} bx_{ij}^{a} \leq \sum_{(o,d) \in \Omega} bX_{ij}^{od} \quad i,j \in N \tag{5.23}$$

$$bx_{ij}^{a} \leq y_{ij}^{a} z_{a}^{w} s_{w} \quad i,j \in N, a \in A, w \in W \tag{5.24}$$

$$q_a = \sum_{i \in N} \sum_{j \in N} \frac{y_{ij}^{a} \times h_{ij}}{v_a} + y_{ij}^{a} \times t_{j}^{a} \quad a \in A \tag{5.25}$$

$$\sum_{a \in A} z_{a}^{w} \times q_a \leq Q_w \quad w \in W \tag{5.26}$$

$$z_{a}^{w} \times mv_w \leq v_a \leq z_{a}^{w} \times Mv_w \quad a \in A, w \in W \tag{5.27}$$

$$z_a^w \times mq_w \le q_a \le z_a^w \times Mq_w \quad a \in A, w \in W \tag{5.28}$$

$$y_{ij}^a z_a^w \le Z_{ij}^w \quad i,j \in N, a \in A, w \in W \tag{5.29}$$

$$\sum_{w \in W} z_a^w \le 1 \quad a \in A \tag{5.30}$$

$$q_a \in \mathbb{Z}^+ \quad a \in A \tag{5.31}$$

$$y_{ij}^a \in \{0,1\} \quad i,j \in N, a \in A \tag{5.32}$$

$$z_a^w \in \{0,1\} \quad a \in A, w \in W \tag{5.33}$$

$$bx_{ij} \in \mathbb{Z}^+ \cup \{0\} \quad i,j \in N \tag{5.34}$$

The objective function (5.22) is to maximize the amount of backbone flow that can be transported in the network $\left(bx_{ij}^a\right)$. The decision variables are four; quantity of vessels (q_a), order of port call $\left(y_{ij}^a\right)$, deployed vessel type for the service (z_a^w), and the amount of shipping flow $\left(bx_{ij}^a\right)$. The former three variables are the same as the profit maximization problem in Chapter 5.2.1.1, which detect the shipping network.

Constraint (5.23) ensures that the shipping backbone flow is lower than the amount of backbone flow. Constraint (5.24) is a capacity constraint indicating that the shipping backbone flow is less than the link's capacity as vessel size. Constraint (5.25) - (5.33) is related to shipping service conditions and are same as Constraint (5.2) – (5.10). Constraint (5.34) defines the domain of decision variables.

We solve the problem by following a simple greedy algorithm. The basic idea of this algorithm is to add a link with a higher flow. We solve the traveling-salesman problem in the algorithm because the links are added without considering the distance between ports. The traveling-salesman problem is formulated as an Integer programming problem and solved by the solver in MATLAB. Note that the obtained results are not an optimum solution but a local solution. We do not necessarily need optimum solutions because the solutions are improved in the next procedures.

[Algorithm]

```
Step. 1 Decide the vessel type to design the shipping service
Step. 2 Select the link with the largest flow and add it to the shipping service
Step. 3 Find the link that connects with the port in the shipping service, has the largest flow, and has
        not been added to the service
Step. 4 Add the found link to the shipping service
Step. 5 Calculate the duration of the shipping service
Step. 6 If the duration is lower than the maximum and higher than the minimum duration, preserve
        the shipping service as a tentative solution
Step. 7 If the duration is less than the maximum duration, go to Step 3
Step. 8 If the shipping service exceeds the maximum duration and the traveling-salesman problem
        has not been solved in the service, solve the traveling-salesman problem and go to Step 5
```

```
Step. 9 If a tentative solution is not obtained, make a new shipping service with the link having the
        largest flow in the link that has not been added to the service
Step. 10 If all vessel types are considered to terminate. Otherwise, go to Step 1
```

5.2.2.2 Network optimization

This part is to optimize the shipping network based on initial shipping services obtained from the Initial network design. Three procedures are included in the network optimization. First, containers flow in the shipping network. Second, we evaluate the shipping network based on the flow. Third, we remake the shipping services. We repeat these three procedures until a stopping criterion is satisfied.

(a) Flowing container

This procedure is to flow the container. The problem is defined in Chapter 5.2.1.2. We need to solve the problem (5.11) with the constraint (5.12) - (5.16). The calculation difficulty of this problem lies in the capacity constraint in constraint (5.12). Here, we solve the problem with the Lagrange heuristic based on Krogsgaard et al. (2018). We reformulate the problem (5.11) and constraint (5.12) with Lagurange multiplier λ_{ij}^{a} to relax the capacity constraint as follows;

$$\min \sum_{a\in A}\sum_{i\in N}\sum_{j\in N}\left(\sum_{(o,d)\in\Omega} c_{ij}^{a}x_{ij}^{a,od} + \lambda_{ij}^{a}\left(y_{ij}^{a}z_{a}^{w}s_{w} - \sum_{(o,d)\in\Omega} x_{ij}^{a,od}\right)\right) + \sum_{a\in A}\sum_{i\in N}\sum_{(o,d)\in\Omega} tc_{i}\left|tx_{i}^{a,od}\right| + \sum_{(o,d)\in\Omega} oc_{od}ox_{od} \tag{5.35}$$

The problem (5.35) with constraint (5.13) - (5.16) is categorized as a shortest-path problem and is solved with the Floyd-Warshall algorithm. We repeat the calculation because the penalty for violating capacity constraint changes in the iteration. The Lagurange multiplier is updated based on the violations of the amount of the capacity constraint. However, it is difficult to find the convergence values for the Lagrange multipliers due to the more than 1000 demand pairs. Thus, we developed a recovery algorithm that invalid flow violating the capacity constraints into a valid flow to satisfy the capacity constraints. This is done by first finding all links where the flow exceeds the capacity. Second, we identify the lowest profit per container. Some or all containers using the route must be moved to an alternative route to reduce the link overflow. Third, we detect the alternative route with the Floyd-Warshall algorithm in the links having spare capacity. This recovery algorithm is introduced where the amount of flow violating capacity is less than the recovery criteria. We repeat the shortest path problem calcualtion by updating the Lagurange multiplier.

(b) Network evaluation

This procedure is to evaluate the shipping network with the container flow. We determine whether we adopt the obtained shipping network as the solution or as a network to be remade. The evaluation function is the profit of the shipping line, which is the problem (5.1) defined in Chapter 5.2.1.1. We adopt the simulated annealing to judge the acceptance of the solution.

Figure 5.6 illustrates the procedure of network evaluation. The acceptance of the solution in simulated annealing is based on the comparison between the current and past solutions. We preserve the shipping service with the highest profit of the shipping line among the results in the past as the best service. If the shipping services have higher profit than the shipping services obtained from the last iteration, we accept the shipping services to be remade. Additionally, we accept the shipping services that have lower profit than the last iteration based on the acceptance probability not staying in the local optimum. The acceptance probability is $exp(Ps - Ps_{last}/temp)$. The $temp$ indicates the temperature and is decreased every iteration using cooling rate. $temp = temp_{last} \times \left(temp_{last}/temp_{first}\right)^{1/maximum\ number\ of\ iteration}$ The stopping criteria of network optimization are that the temperature achieves a final temperature. The cooling rate is based on the maximum number of iterations of calculation of network optimization, initial and final temperature. We set those setting for simulated annealing based on Ribeiro et al. (2014) and Real et al. (2021).

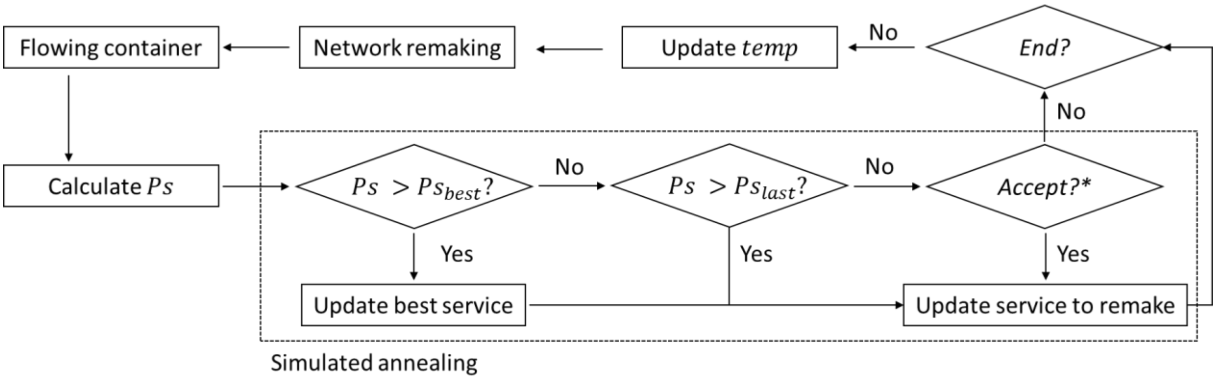


Figure 5.6 Procedure of network evaluation

(c) Network remaking

This procedure is to remake the shipping network. We remake the shipping network with an Adaptive Large Neighborhood Search (ALNS) to satisfy the constraints (5.2) – (5.10). The ALNS is an algorithm using several large neighborhoods in an adaptive way. Specifically, we choose to destroy operators to remove nodes from the shipping services routes and repair operators to reconstruct the solution. Operators are selected according to an adaptive probabilistic mechanism derived from the score of each operator in ALNS (Real et al., 2021).

We adopt the following five destroy operators. Note that the operator “Random service” is applied every five iterations without considering the probability of the operator.

- Random choose: A service is randomly chosen. A port in the service is randomly chosen and removed from the service.

- Cost savings: A service is randomly selected. Calculate the difference between the total cost of service with and without each port in the service. A port with the largest difference is removed.
- Capacity inefficiency: A port with the least effective use of link capacity is removed.
- Shaw removal: A port is randomly chosen. The closest port that connected with the first chosen port is removed.
- Random service: A service is randomly chosen and removed.

We adopt the following four repair operators. Note that we first choose a service to repair all operators.

- Greedy demand: A port with the greatest demand per distance in the chosen service is inserted.
- Greedy distance: A port with the shortest distance to the chosen service is inserted.
- Random choose: A port is randomly selected. Insert the port to the chosen service to minimize the difference between the total distance of the service with and without the port.
- Unserved port: A port with no port of call is randomly selected. Insert the port to the chosen service to minimize the difference between the total distance of the service with and without the port.

The probability to choose operator m in iteration n is $\pi_{m,n}/\sum_m \pi_{m,n}$ with the weight of operator $\left(\pi_{m,n}\right)$. Equation (5.36) show the weight.

$$\pi_{m,n} = (1-\gamma)\pi_{m,n-1} + \gamma \frac{\delta_{m,n-1}}{max\left(\theta_{m,n-1}, 1\right)} \tag{5.36}$$

We set the weight to reflect the performance of each operator in the last iteration with the number of times operator m in the last iteration $\left(\theta_{m,n-1}\right)$ and the score of operators $\left(\delta_{m,n-1}\right)$. The score of operators increases when the operator results in better solutions. Specifically, we set the score $\delta_{m,n-1}$ as follows; (1) σ_1 if the operator results in the new best profit, (2) σ_2 if the operator results in a better profit than the previous iteration, (3) σ_3 if the operator results in a worse profit but better omission cargo, and (4) 0 otherwise. The parameters $(\sigma_1, \sigma_2, \sigma_3\ and\ \gamma)$ are non-negative values and control the impact of the performance of operators in the last iteration on the probability of being be chosen. We set those setting for ALNS based on Ropke and Pisinger (2006) and Real et al. (2021).

5.2.2.3 Overview of the algorithm

The developed the backbone algorithm was coded in MATLAB and run on an Intel® Core™ i7-9700 processor with 16 GB of RAM. The computation time of an experiment is about a half day. We show the whole algorithm in Appendix K. The modification of backbone algorithm from Krogsgaard et al. (2018) is the adoption of ALNS instead of variable large neighborhood search (VNS). The difference of ALNS and VNS is the search area as neighborhood. ALNS has operates on structurally different neighborhoods and VNS operates on one type of neighborhood with variable depth (Pisinger and Ropke 2007). Additionally, we adopt the simulated annealing in the network evaluation. The simulated annealing realizes the search in a wider range solution with accepting the worse solution. The two modification is the novelty of this study in the studies about LSNDP.

5.2.3 Simulation with LSNDP

5.2.3.1 Input and reproductivity

We use the input data in LINER-LIB proposed by Brouer et al. (2014). Seven vessel types are analyzed, shown in Table 5.2. The conditions of vessel type are based on Krogsgaard et al. (2018). Larger vessels, typically traveling between continents, get longer rotations than smaller vessels doing feeder service. Especially the largest class, named Super_panamax, is available at either 0 or 10 because the largest vessels should be used for intercontinental routes with high volume, not to split the vessels into two different services (Krogsgaard et al., 2018).

Table 5.2 Condition about vessel types

Vessel type	Vessel size s_w	Vessel speed $[mv_w,Mv_w]$	Navigation time $[mq_w,Mq_w]$	Fleet quantity Q_w
Super_panamax	7500	[12, 22]	[10, 10]	10
Post_panamax	4200	[12, 23]	[7, 14]	91
Panamax_2400	2400	[12, 22]	[6, 12]	161
Panamax_1200	1200	[12, 19]	[4, 10]	124
Feeder_800	800	[10, 17]	[2, 8]	77
Feeder_450	450	[10, 14]	[2, 5]	38

Source: Krogsgaard et al. (2018)

Figure 5.7 indicates the profit values in six parameter sets[2]. We repeat the three network optimization procedures, which include flowing container, network evaluation, and remaking network, 500 times. Set 3 realizes the shipping network with the highest profit of the shipping line. We compare the container throughput obtained in the simulation as the estimated throughput and actual data in 2020, the latest data, to check the reproductivity of the obtained result in Figure 5.8. It is worth noting that we compare the ports with the highest container throughput in 2020. As shown in Figure 5.8, the model cannot fully reproduce the actual data. Especially some Asian ports, such as Port Klang and Busan, are overestimated and some Chinese ports, such as Shanghai and Shenzhen, are underestimated. The main reason for the difference between the result and the actual ranking is that the LINER-LIB is biased and differs from the actual situation. For example, although Tokyo port in Japan has a greater demand than Kobe port in actual maritime transport, Kobe port has a larger amount of demand in LINER-LIB. As for the simulation targets of cooperation and the competitors, Table 5.3 shows the comparison result. We compare the ranking of the total capacity of calling vessels in port, labeled as *capacity*, container throughput labeled as *cargo*, and actual container throughput of 2020 in Lloyd's list labeled as 2020. Japanese ports, including Kobe, Osaka, and Yokohama ports other than the cargo of Osaka, are

---

[2] We analyze the following six parameter sets about a score of operators in ALNS
Set 1: $\sigma_1 = 3, \sigma_2 = 2, \sigma_3 = 1$, Set 2: $\sigma_1 = 1, \sigma_2 = 3, \sigma_3 = 2$, Set 3: $\sigma_1 = 2, \sigma_2 = 1, \sigma_3 = 3$
Set 4: $\sigma_1 = 3, \sigma_2 = 1, \sigma_3 = 2$, Set 5: $\sigma_1 = 1, \sigma_2 = 2, \sigma_3 = 3$, Set 6: $\sigma_1 = 2, \sigma_2 = 3, \sigma_3 = 1$

overestimated. However, the values of competitors such as Busan, Hong Kong, and Kaohsiung ports are larger than Kobe and Osaka ports. The obtained network has the reproductivity to analyze the comparison between those ports, which is the objective of this chapter.

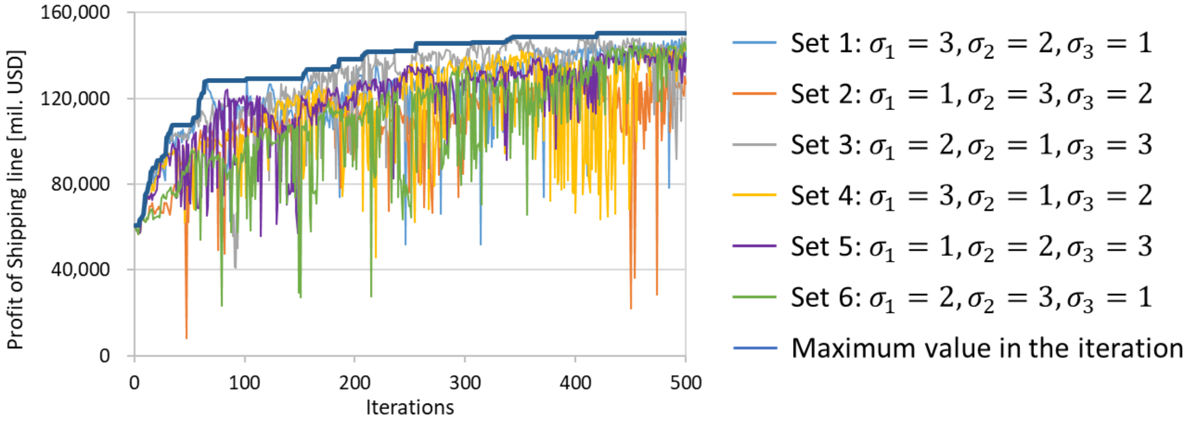


Figure 5.7 Profit of shipping line obtained from each parameter set

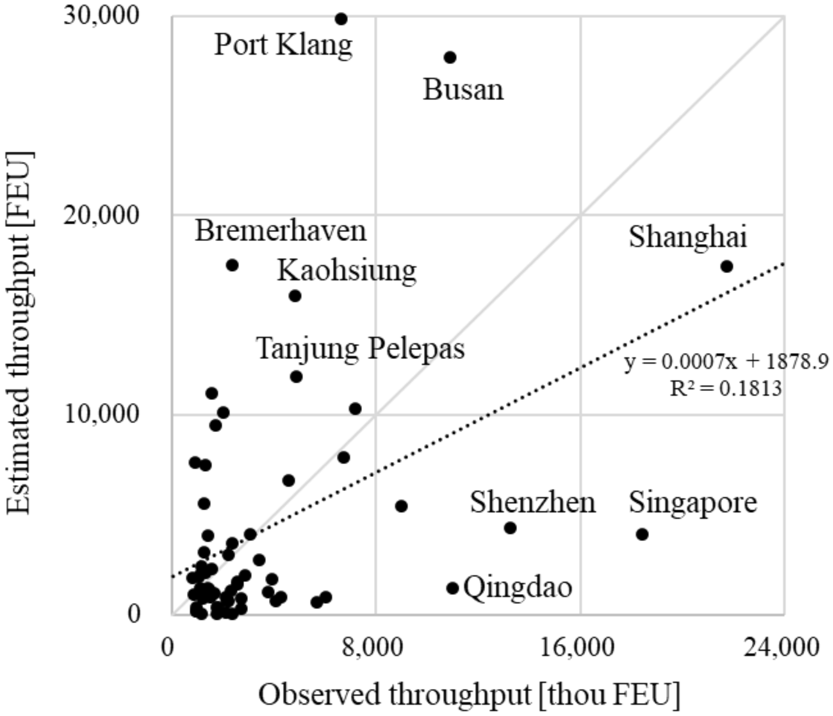


Figure 5.8 Reproducibility of cargo (solid line: forty-five-degree line, dot line: approximate line from the observed data)

Table 5.3 Comparison to check the reproductivity in cooperative ports and competitors

Port	Capacity	Cargo	2020
Busan	674,400 (2)	27,940 (2)	10,912,000 (5)
Kobe	227,200 (18)	2,128 (40)	1,323,533 (50)
Osaka	209,200 (20)	58 (171)	1,176,125 (57)
Hong Kong	583,600 (5)	5,464 (18)	8,976,500 (6)
Kaohsiung	388,150 (10)	15,988 (5)	4,810,831(13)

Yokohama	245,400 (16)	7,471 (14)	1,330,811 (49)

* The values given in parentheses are the ranking in the 201 ports as simulation targets.

5.2.3.2 Scenario analysis

This study analyzes the impact of cooperation between Kobe and Osaka ports on shipping network design. We prepared five scenarios, as shown in Table 5.4. Depth and port charge scenarios focus on improving the port facility and cost at the port, which are the important determinants of the competitiveness of ports (Yuen et al. 2012), respectively. The depth of Kobe and Osaka ports are changed to analyze the impact on the network design of the introduction of deeper depth to allow larger vessels to call on the port as a draft scenario. Note that Kobe and Osaka ports are already deeper than 13.5 m in 2022, and values in LINER-LIB are not 13.5 m. The port charge is reduced to analyze the lower cost impact on the network design as a port charge scenario. We assume that the economy of scale realizes the improvements in port cooperation. Cargo increase and concentration scenario focus on the change of demand, which are influential factors in the network change and the role of the port in the network (Wilmsmeier and Notteboom, 2011). The increase in cargo demand in Kobe and Osaka ports is simulated as a cargo increase scenario. We assume that the increase is realized by successful marketing with cooperation. The cargo of Osaka port is concentrated in Kobe port as a concentration scenario. We assume the division of function that Kobe port is concentrated as a large port by port cooperation. Finally, we simulate above all contents as all scenarios.

Table 5.4 Scenario overview

Scenario	Overview
Draft scenario (scenario 1)	Change the depth of Kobe and Osaka ports to 13.5m
Port charge scenario (scenario 2)	Reduce 20% of port charge in Kobe and Osaka ports
Cargo increase scenario (scenario 3)	Increase 20% cargo in Kobe and Osaka ports
Concentration scenario (scenario 4)	Concentrate both cargoes to Kobe as Hanshin port
All scenario (scenario 5)	Implement all in scenarios 1-4

5.2.3.3 Measures in network

We compare the change of shipping network design in scenarios by the network structure. Specifically, shipping networks are changed into a network with a graph of all linkages proposed by Ducruet and Notteboom (2012a). If the two ports belong to the same shipping service, they are connected, although they are not adjacent calls. An example of a network with the graph of all linkages is shown in Appendix L. The network has the links weighted by the sum of port capacity calling on the port. We analyze the network with measures in network science to reveal the change in network configuration and port competitiveness of Kobe, Osaka, and other competitive ports.

We analyze the network with measures in Table 5.5. A degree is the number of links connected to the node, which indicates the number of ports for direct shipping with one shipping service. Strength is the sum of the weighted link of the node, which indicates the total capacity of calling vessels. Betweenness centrality is the number of shortest paths going through the node, which indicates the accessibility of ports in the network. We calculate the two types of betweenness centrality with non-weighted and weighted distance. Non-weighted distance means the distance between nodes is the number of links. Weighted distance means the distance characterized by the weight between nodes. We calculate the distance between nodes as the inverse of weight to reflect the characteristic that links with higher weights have higher capacity. Opsahl et al. (2010) suggested the importance of analyzing the two centralities for new findings in the same network. In this study, for example, high non-weighted and low weighted betweenness indicates that many small vessels call on the port and high non-weighted and high weighted betweenness suggests that many large vessels call on the port. We show the example of non-weighted and weighted distance in Appendix M.

Table 5.5 Overview of measures to compare the networks

Name	Overview
Degree	Number of links connected to the node
Strength	Sum of weights of links of the node
Betweenness centrality	Number of shortest paths going through the node

We analyze the similarity of networks with the highest profit of shipping lines in six parameter sets related to the score of operators in ALNS (σ_i) before calculating the measures. Equation 5.37 shows the weighted similarity between networks 1 and 2 based on Gelardi et al. (2021).

$$(similarity) = \frac{\sum_{i>j} l_{ij}^{(1)} l_{ij}^{(2)}}{\sqrt{\sum_{i>j} \left(l_{ij}^{(1)}\right)^2} \sqrt{\sum_{i>j} \left(l_{ij}^{(2)}\right)^2}} \tag{5.37}$$

where, $l_{ij}^{(1)}$ is the weight of links between nodes i and j in the network 1. If the value is close to 1, the two networks become similar. Table 5.6 shows the similarity of the network among base and scenarios 1-4. The similarities are about 0.7, which indicates that the networks are changed. We can point out the two reasons for the change. The first reason is that port cooperation between Kobe and Osaka ports influences the network configuration. Second reason is that solution achieves different local optimums. We cannot distinguish which reason is deterministic. Therefore, we compare the average value of each measure in Table 5.5 of the top three parameter sets in each scenario to smooth out the fluctuation by the local optimum with reflecting the impact of cooperation.

Table 5.6 Similarity of network among base and scenario 1-4

	Base	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Base	1.000	0.719	0.679	0.724	0.695
Scenario 1	0.719	1.000	0.666	0.727	0.694
Scenario 2	0.679	0.666	1.000	0.667	0.669
Scenario 3	0.724	0.727	0.667	1.000	0.713
Scenario 4	0.695	0.624	0.669	0.713	1.000

5.3 Results and Discussion

5.3.1 Analysis about scenario 1-4

Table 5.7 shows the degree and strength of networks about base and scenarios 1-4. The values are changed from the base in each scenario. For example, although scenario 1 has the highest average degree and strength, the maximum strength value is the lowest in all scenarios. This indicates that vessels calling on the large dominant ports in other scenarios are now calling on the other small ports. In scenarios 1 and 2, Bremerhaven port has the highest degree values. The Bremerhaven port is the only port that has the highest values of degree and strength other than Asian ports such as Tanjung Pelepas and Singapore. Although Bremerhaven port did not connect with Kobe and Osaka in base, some service calls on Bremerhaven and Kobe or Osaka ports in scenarios 1 and 2. Singapore port has the maximum degree and strength in scenario 3 and becomes the dominant port. The dominant port in the network is changed due to the cooperation as cargo increases (scenario 3). Those results show that the focus of the cooperation changes the impact of port cooperation on the network.

Table 5.7 Degree and strength in the networks of base and scenario 1-4

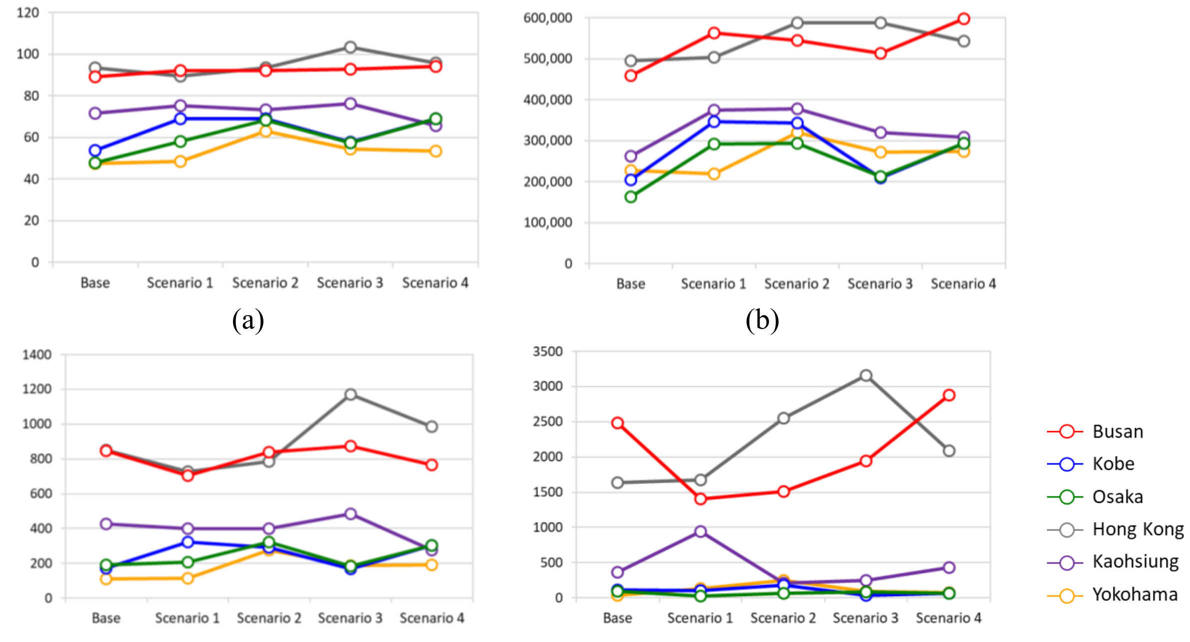
	Average degree	Average strength	Maximum degree	Maximum strength
Base	27	80,091	103 (Tanjung Pelepas)	600,967 (Tanjung Pelepas)
Scenario 1 (Draft)	29	88,367	108 (Bremerhaven)	577,433 (Shanghai)
Scenario 2 (Port charge)	27	84,962	103 (Bremerhaven)	608,750 (Singapore)
Scenario 3 (Cargo increase)	27	83,593	112 (Singapore)	634,533 (Singapore)
Scenario 4 (Concentration)	27	84,051	106 (Tanjung Pelepas)	598,183 (Busan)

Figure 5.9 shows the degree, strength, and betweenness centralities of Asian ports. The values of degree, strength, and non-weighted betweenness of Kobe and Osaka ports in each scenario increase from the base. However, the values are less than Busan port as a strong competitor. The large ports such as Busan and Hong Kong ports compete with each other. Specifically, if Busan's weighted betweenness is lower, Hong Kong's value is higher, and vice versa. This result indicates that although the cooperation can

affect the competition, Kobe and Osaka ports cannot obtain stronger competitiveness than a competitor such as Busan port.

The impacts on competitiveness are different from the scenarios. For example, although the values of Kobe and Osaka ports are increasing from the base in scenario 3, the values are lower than in other scenarios. The degree and non-weighted betweenness values in scenario 4 are higher than in the Kaohsiung port. The importance of considering the focus of cooperation for the competition with other ports. As for the weighted betweenness, the values do not drastically change in each scenario, which indicates that cooperation cannot result in many large vessel callings.

Additionally, the cooperation between Kobe and Osaka ports influences other ports, such as Yokohama port in Japan. The impacts are different with scenarios. Especially value of Yokohama ports is the lowest in scenario 1 and is highest in scenario 2. The reason for the impact on ports other than cooperative ports is that some shipping services tend to call on nearby ports. Some shipping services newly call on Kobe and Osaka ports by the cooperation and also calls on ports in East Asia near the two ports to increase the income of the service. The ease to call changes depending on the distance between the two ports. For example, the distance of a service that calls on Tanjung Pelepas, Busan, and Kobe ports is 3197 nautical miles, and the distance of a service that calls on Tanjung Pelepas, Hong Kong and Kobe ports is 2863 nautical miles. The service calling on Tanjung Pelepas and Kobe ports is more accessible to call on Hong Kong than Busan ports by the shorter distance. The service newly calling on the Kobe and Osaka ports are different in each scenario, which results in the different impact of cooperation on the port other than cooperative ports.



(a) (b)

(c) (d)

Figure 5.9 Values of measures in each port (a) degree (b) strength (c) non-weighted betweenness centrality (d) weighted betweenness centrality

5.3.2 All scenario (scenario 5)

Scenario 5 analyzes the case where contents in scenarios 1-4 are implemented at the same time. Table 5.8 shows the comparison of values between base and scenario 5. All values of Kobe and Osaka ports increase from the base and are larger than Kaohsiung port. Although the values are less than Busan port, the difference in values among Kobe, Osaka, and Busan ports are not so large, which indicates that the two ports have become competitive enough to compete with Busan port. Especially, weighted betweenness values are increased, and many large vessels call on Kobe and Osaka ports.

The degree and strength of Busan ports increase from the base. Betweenness centralities decrease from the base and the hub function with high accessibility of port in the network is shifted to another port. The increased betweenness centralities of Kobe and Osaka ports indicate that the hub function shifts to the two ports. On the other hand, the values of Hong Kong port drastically increase from the base, which suggests the function also shifts to Hong Kong. The new strong competitor appears with the cooperation. As the difference among Kobe, Osaka, and Hong Kong ports shows, the competitiveness of Kobe and Osaka ports are less than a new strong competitor.

Table 5.8 Values of measures of base and scenario 5 (Sce. 5)

	Degree		Strength		Betweenness			
					Non-weighted		Weighted	
	Base	Sce. 5	Base	Sce. 5	Base	Sce. 5	Base	Sce. 5
Busan	89	93	458,733	528,000	849	696	2,486	886
Kobe*	54	81	204,267	471,933	173	442	108	533
Osaka*	48		163,067		193		91	
Hong Kong	94	106	495,750	631,250	849	1,048	1,631	3,036
Kaohsiung	72	81	263,133	362,000	425	517	362	339
Yokohama	48	63	227,983	339,000	111	214	31	64

* Kobe and Osaka ports are consolidated as Hanshin port

Figure 5.10 shows the change of degree and strength from base to scenario 5 of the top-fifty ports with the highest strength in base. The breakdown of all ports is shown in Appendix N. Degree and strength in many Asian ports increase and in many European ports decrease from the base. The shipping line deploys many vessels in Asia instead of Europe in scenario 5. Some ports have different impacts in the same region. Specifically, the degree and strength values of Tanjung Pelepas port decrease, unlike other Asian ports, and the values of Felixstowe port increase, unlike other European ports. Ports in regions other than Asia and Europe, such as North America, do not have a clear tendency. The strength increase in Los Angeles port indicates that large vessels call on the port. The impacts on the shipping network by port cooperation change depending on the port.

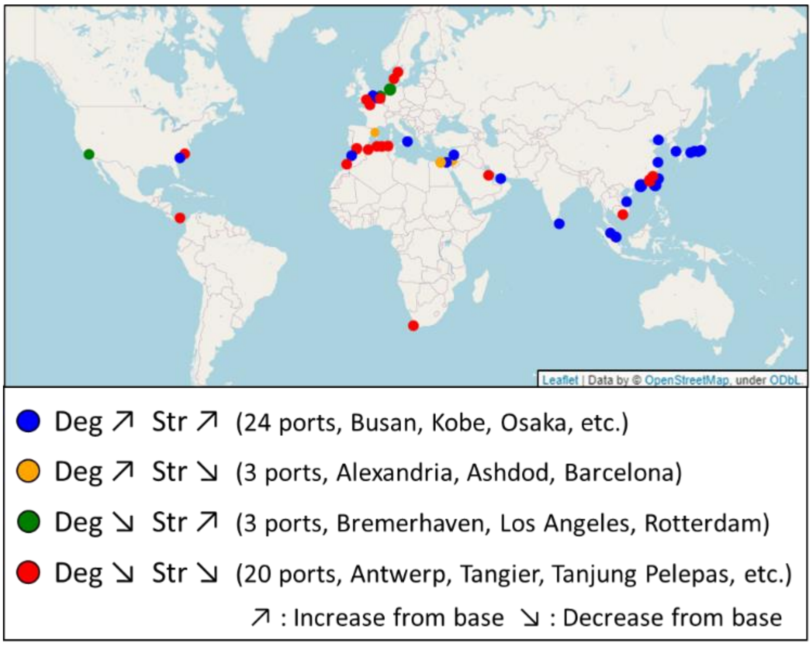


Figure 5.10 Degree (Deg) and Strength (Str) of top-fifty ports with highest strength in base

5.3.3 Discussion

Based on the results reported in the previous section, the findings of this study regarding the impact of port cooperation on network design can be summarized as follows.

First, cooperation influences the competitiveness of cooperative ports. The measures of Kobe and Osaka ports increase from the base in each scenario. However, the values are less than Busan port as a strong competitor. Busan port competes with other large ports. This result indicates that although port cooperation contributes to increasing competitiveness, the cooperative port cannot obtain stronger competitiveness than the competitor. Policymakers engaged in port management must build another port strategy to increase the competitiveness of ports.

Second, the cooperation influences network configuration and the port other than the cooperative ports. The impact change depending on the port. Specifically, degree and strength increase in Asian ports and decrease in European ports. Additionally, the impacts change depending on the cooperative scenario. The impacts are due to the calling of new services on cooperative ports. The service calls on cooperative ports and near ports, resulting in the network configuration change. The result suggests that policymakers planning to build the cooperative strategy need to consider the impact on ports other than cooperative ports.

Third, cooperation in implementing all contents, including draft, port charge reduction, cargo increase, and concentration, realize the competitiveness enough to compete with Busan port. The hub function of Busan port with high accessibility of port in the network is shifted to Kobe and Osaka ports by the cooperation. However, the hub function is also shifted to Hong Kong port. Hong Kong port has stronger competitiveness than Kobe and Osaka ports. The influence of cooperation results in the appearance of a new strong competitor. An additional port strategy is needed to compete with the new competitor.

5.4 Conclusion

The objective of this chapter is to reveal the effectiveness of port cooperation for competition from the perspective of port and shipping lines as the supply in maritime transport. We set two objectives as Objective 5.1 and 5.2. Objective 5.1 is to predict the liner shipping network design by the shipping line. Objective 5.2 is to evaluate the change in the shipping network by port cooperation.

This chapter analyzed the cooperation between Kobe and Osaka ports to evaluate the impact of port cooperation on shipping network design by the shipping line. We developed the backbone flow algorithm for solving the liner shipping network design problem, defined as designing a set of weekly services to achieve Objective 5.1. The algorithm has two main parts that include initial network designing and network optimization and has five procedures making backbone flow, making initial network, flowing container, network evaluation, and remaking network. We analyze the five scenarios, which include depth, port charge, cargo increase, cargo concentration, and all scenarios to show the different impacts on the shipping network by cooperative scenarios to achieve Objective 5.2. The results suggest the following three conclusions regarding port cooperation.

The results suggest the following three conclusions. First, although port cooperation contributes to increasing competitiveness from the perspective of the shipping line, the cooperative port cannot obtain stronger competitiveness than the competitor. Second, the cooperation influences on the network configuration and the port other than the cooperative ports. The impact change depending on the port. Third, cooperation in implementing all contents, including draft, port charge reduction, cargo increase, and concentration, realize the competitiveness enough to compete with Busan port. The influence of cooperation results in the appearance of a new strong competitor. The findings can assist policymakers engaged in port management by suggesting the estimation of shipping networks for the realization of higher port competitiveness than the strong competitor by the port cooperation.

This chapter has several limitations. For example, we analyze the shipping network design by one shipping line. Multiple shipping lines design their own shipping services while competing with each other in actual maritime transport. The competition might influence the network design and freight rate. Additionally, the analyzed ports are 201 ports all over the world. We do not analyze all ports in the world especially local ports. The transshipment from local ports might influence the network design.

CHAPTER 6: Conclusion

6.1 Summary and conclusions

The number of container ports cooperating to improve port productivity or profitability has been increasing. These cooperative strategies can be divided into two categories based on the focus of cooperation: regional welfare and competition. Many previous studies about port cooperation have focused on regional welfare cooperation. Cooperation for competition has not been fully analyzed. There is a research gap regarding whether cooperation is effective for competition. Based on this background, this dissertation aims to reveal the effectiveness of port cooperation in competition with a strong competitor. This dissertation first analyzes the impact of port cooperation on a port hierarchy based on network analysis. Second, this dissertation focuses on port competition from the perspective of the relationship between port and shipper. Finally, this dissertation focuses on port competition from the perspective of the relationship between port and shipping line. The main findings of this dissertation are summarized by chapter as follows:

Chapter 2 reviews previous studies with three categories; port cooperation, port competition, and network design. The review reveals the three research gaps related to cooperation for competition. The first gap is that the conditions for success the cooperation for competition have not been revealed, which is fulfilled by the achievement in Chapter 4. The second gap is that change in port competitiveness by port cooperation has not been analyzed in the maritime transport network, which is fulfilled by the achievement in Chapter 3. The third gap is that the network designing of the shipping line as a supplier has not been analyzed in port cooperation, which is fulfilled by the achievement in Chapter 5.

Chapter 3 analyzes the cooperation of the Hanshin port (Kobe and Osaka) to evaluate the impact of port cooperation on the network. We applied graph theory to the Japanese cargo network, which included several complex network measures and link predictions. The Japanese cargo network was constructed as a graph with ports as nodes and undirected links weighted by the amount of container flow. Three networks were analyzed, including 2008, 2018 (Base), and 2018 (Coop). We compared the 2008 and 2018 (Base) networks to evaluate how the current cooperation between Kobe and Osaka ports affected the competitiveness. Furthermore, we compared 2018 (Base) and 2018 (Coop) networks to demonstrate the expected impact of port cooperation in the network. The results suggest the following three conclusions.

First, the transshipped cargo to/from local Japanese ports increased in the Kobe and Osaka ports. However, the degrees in Kobe and Osaka decreased, and the expansion of the trunk line in Kobe and Osaka was not achieved. As for the strong competitor, the degree and strength of the Busan port increased in almost all regions. Kobe and Osaka did not attain a higher position in the port hierarchy than Busan due to connectivity. Second, synergistic cooperation via node aggregation contributed to a higher position in the port hierarchy. However, cooperation through port aggregation alone is not enough to realize higher connectivity because most ports connected to cooperative ports are overlapped. The cooperation did not construct higher interconnected relationships with local Japanese ports and did not attain higher centralities than the Busan port. Additional port policies are needed to better achieve a higher position in the port hierarchy. Third, a change in network configuration due to cooperation affects the connection probability of the ports. The policy to attract new services is changed by building cooperative relationships because of the different connection probabilities. However, connecting with a higher connection probability in a graph does not always effectively strengthens centrality. The connecting ports need to be selected to attain a higher position in the port hierarchy, whether building cooperation or not.

Chapter 4 developed two different models to derive cooperation levels and cooperation types. Specifically, a game theoretical model to simulate the relationships between ports and shippers in a linear city is developed for the cooperation level in Chapter 4.2. Bi-level optimization model that is applied to a case study for the Kobe and Osaka ports in Japan is developed for the cooperation type in Chapter 4.3. Chapter 4.2 focuses on three ports, which include ports 1, 2, and 3 in the virtual city, considering the cooperation or competition between ports 1 and 2 and competition between ports 2 and 3. Chapter 4.3 focuses on three ports, which include Busan, Kobe, and Osaka ports, considering the cooperation or competition between Kobe and Osaka in hinterland cargo and competition between Kobe and Busan in transshipment cargo.

Chapter 4.2 suggested the following three conclusions. First, port cooperation is an effective strategy for the competition from the shipper's perspective with increasing cargo throughput in a competitive area. The cargo in a competitive area reaches a maximum when the port achieves a balance between cooperation and competition at the optimum cooperation level. Second, the optimum cooperation levels for regional welfare and competition are different. In many situations, cooperation for port access requires a higher level of cooperation for competition than for regional welfare. This is because the required cooperation effects change depending on the type of cooperation and the situation. Finally, the loss of welfare in the regional market and cargo in the competitive market with incorrect cooperation changes depending on the port situation. The loss is larger in areas with a larger gap in the optimum cooperation levels between motivations, especially in low public-level ports.

Chapter 4.3 suggested the following two conclusions. First, cooperation does not contribute to improving competition about Southeast Asian cargo in all scenarios and cooperation levels. On the other hand, cooperation contributes to improvement in the competition for North American cargo in some scenarios. Optimum cooperation types change depending on the focusing market. Second, cooperation contributes to improvement in the competition are low cooperation levels in shipping cost and port operation scenarios. Effective cooperative strategy for competition in Kobe and Osaka ports can only be realized under limited conditions from the shipper's perspective.

Chapter 5 analyzed the cooperation between Kobe and Osaka ports to evaluate the impact of port cooperation on shipping network design by the shipping line. A linear shipping network design problem is defined as the task of designing a set of weekly services, assigning vessels to the services, and flowing the demand through the resulting network. The answer to the problem indicates the deployment of shipping services to ports around the world. We developed the backbone flow algorithm for solving the problem. We use the LINER-LIB, which is a data set containing ports, including port call cost, cargo handling cost and draft restrictions, distances between ports considering draft and canal traversal, vessel-related data for capacity, cost, speed interval, and bunker consumption, and a commodity set with quantities, revenue, and maximal transit time. We analyze the five scenarios, which include depth, port charge, cargo increase, cargo concentration, and all scenarios to show the different impacts on the shipping network by cooperative scenarios. The results suggest the following three conclusions.

First, measures of Kobe and Osaka ports increase from the base in each scenario. However, the values are less than Busan port as a strong competitor. Although port cooperation contributes to increasing competitiveness from the perspective of the shipping line, a cooperative port cannot obtain stronger competitiveness than the competitor. Second, the cooperation influences on network configuration and the port other than the cooperative ports. The impact change depending on the port. The service calls on cooperative ports and near ports, resulting in the network configuration change. Third, cooperation in implementing all contents, including draft, port charge reduction, cargo increase, and concentration, realize the competitiveness enough to compete with Busan port. However, the hub function is also shifted to Hong Kong port. The influence of cooperation results in the appearance of a new strong competitor.

The findings in this dissertation conclude that cooperation contributes to the increase of competitiveness of cooperative ports. However, the competitiveness is weaker than the strong competitor. Cooperation is a trigger to increase competitiveness. An additional strategy to continuously increase the competitiveness for stronger competitiveness than the competitor, which is not necessarily port cooperation, is needed.

6.2 Future direction

The directions for future research can be discussed by addressing the several improvements of studies in this dissertation. The future directions are as follows.

Common future direction in Chapter 3-5

Studies in this dissertation do not consider the difficulty of building port cooperation, such as compliance with the regularity of competition and governance involving decision-making at the highest levels in port cooperation, as discussed by Yoshitani (2018) and Knatz (2018). The difficulty of each cooperative scenario, such as requiring monetary and non-monetary costs, differs. We can analyze the cooperation considering the difficulty of future work. Future work requires a more practical view to analyze the difficulty.

Future direction related to Chapter 3 and 5

Chapter 3 analyzes the simple cooperation with ports worldwide, including local ports. Chapter 5 explores the various port cooperation with ports, not including ports all over the world especially in local ports. The analysis of the various port cooperation with ports worldwide, including local ports, is future work. Future work can analyze the impact of the local port on network design.

Future direction related to Chapter 4 and 5

Chapter 4 simulates the relationship between the port and the shipper. Chapter 5 simulates the relationship between the port and the shipper. The relationship among the three parties, that is, the relationship among the port, shipper, and shipping line, is not analyzed. Future work can extend the studies of this dissertation by considering the relationships of the three parties. The future work explores a more realistic situation than this dissertation and requires computational difficulty.

Future direction related to Chapter 3

Chapter 3 analyzes the Japanese cargo network in 2008 and 2018. The network change from 2008 to 2018 was affected by several factors other than port cooperation between Kobe and Osaka ports. Other changes, such as the bankruptcy of Hanjin Shipping, influenced the Japanese cargo network. An analysis to distinguish whether a network change occurred due to cooperation or other factors is needed in future work.

Future direction related to Chapter 4

Chapter 4 analyzes the cooperation or competition among the three ports. Specifically, Chapter 4.2 focuses on the three ports in a linear city, and Chapter 4.3 focuses on Kobe, Osaka, and Busan ports. Port competes with several nearby ports, not necessarily three. The optimum cooperative strategy might be changed. Thus, future work can analyze the relationships among more ports. Second, the cooperation level z in Chapter 4.2 and z_{ij} in Chapter 4.3 is a benchmark for making a cooperative port strategy. The values do not indicate detailed port cooperative strategies. Thus, future work can analyze the more detailed cooperative scenarios with a more practical view.

Future direction related to Chapter 5

Chapter 5 analyzes the shipping network design by one shipping line. Multiple shipping lines design their own shipping services while competing with each other in actual maritime transport. The competition among shipping lines might influence the network design. The analysis of the network design with considering the competition is future work.

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Appendices

Appendix A:Ports that maximize each centrality or have the highest connection probability at the Kobe or Osaka ports for Chapter 3

Table A.1 Ports that maximize each centrality or have the highest connection probability

2018 (Base)	High probability at Kobe*	Shimizu (Japan)	Felixstowe (United Kingdom)	Antwerp (Belgium)	Kawasaki (Japan)	Yokkaichi (Japan)
	Max. Betweenness at Kobe	Changchun (China)	Mackay (Australia)	Toluca (Mexico)	Mississauga (Canada)	East London (South Africa)
	High probability at Osaka*	Tokyo (Japan)	Kawasaki (Japan)	Nagoya (Japan)	Long Beach (United States)	Shimizu (Japan)
	Max. Betweenness at Osaka	Changchun (China)	East London (South Africa)	Mackay (Australia)	Toluca (Mexico)	Mississauga (Canada)
2018 (Coop)	High probability at Hanshin*	Marseille-Fos (France)	Shimizu (Japan)	Felixstowe (United Kingdom)	Yokkaichi (Japan)	Kawasaki (Japan)
	Max. Betweenness at Hanshin	Changchun (China)	Mackay (Australia)	Toluca (Mexico)	Mississauga (Canada)	East London (South Africa)

* The highest connection probability ports are shown from left to right

Appendix B: Required conditions for boundaries for Chapter 4

Boundaries located between locations of ports ($l_{01} < d_1 < l_{12} < d_2 = 0 < l_{23} < d_3 < l_{34}$). Thus,

$$d_1 - l_{01} = \frac{V - w_1 - (1 - \alpha \cdot z)ch_1}{(2 - 2\alpha \cdot z)cs} > 0$$

$$l_{12} - d_1 = \frac{-(1 - \alpha \cdot z)cs \cdot d_1 - (w_1 - w_2) - (1 - \alpha \cdot z)(ch_1 - ch_2)}{(2 - 2\alpha \cdot z)cs} > 0$$

$$0 - l_{12} = \frac{-(1 - \alpha \cdot z)cs \cdot d_1 + (w_1 - w_2) + (1 - \alpha \cdot z)(ch_1 - ch_2)}{(2 - 2\alpha \cdot z)cs} > 0$$

$$l_{23} - 0 = \frac{cs \cdot d_3 - (w_2 - w_3) - (1 - \alpha \cdot z)ch_2 + ch_3}{(2 - \alpha \cdot z)cs} > 0$$

$$d_3 - l_{23} = \frac{(1 - \alpha \cdot z)cs \cdot d_3 + (w_2 - w_3) + (1 - \alpha \cdot z)ch_2 - ch_3}{(2 - \alpha \cdot z)cs} > 0$$

$$l_{34} - d_3 = \frac{-w_3 - ch_3 + V}{cv} > 0$$

Since $0 \le \alpha \le 1, 0 \le z \le 1, cs > 0, cv > 0$, input values must satisfy following conditions:
$V > w_1 + (1 - \alpha \cdot z)ch_1,\ V > w_3 + ch_3,$
$-(1 - \alpha \cdot z)cs \cdot d_1 > w_1 - w_2 + (1 - \alpha \cdot z)(ch_1 - ch_2) > (1 - \alpha \cdot z)cs \cdot d_1$ and
$cs \cdot d_3 > w_2 - w_3 + (1 - \alpha \cdot z)ch_2 - ch_3 > -(1 - \alpha \cdot z)cs \cdot d_3$

Appendix C: Calculation of differentiation of cargo for Chapter 4

$$\frac{\partial x_1}{\partial w_1} = \frac{\partial l_{12}}{\partial w_1} - \frac{\partial l_{01}}{\partial w_1} = -\frac{1}{(2 - 2\alpha \cdot z)cs} - \frac{1}{(1 - \alpha \cdot z)cv}$$

$$\frac{\partial x_2}{\partial w_2} = \frac{\partial l_{23}}{\partial w_2} - \frac{\partial l_{12}}{\partial w_2} = -\frac{1}{(2 - \alpha \cdot z)cs} - \frac{1}{(2 - 2\alpha \cdot z)cs}$$

$$\frac{\partial x_3}{\partial w_3} = \frac{\partial l_{34}}{\partial w_3} - \frac{\partial l_{23}}{\partial w_3} = -\frac{1}{cv} - \frac{1}{(2 - \alpha \cdot z)cs}$$

Since $0 \le \alpha \le 1, 0 \le z \le 1, cs > 0, cv > 0, \frac{\partial x_1}{\partial w_1} < 0, \frac{\partial x_2}{\partial w_2} < 0, \frac{\partial x_3}{\partial w_3} < 0$

Appendix D: Components of coefficient(A) and constant matrix(b) for Chapter 4

$$A=\begin{pmatrix} \frac{-1}{(1-\alpha\cdot z)cs}+\frac{-2}{(1-\alpha\cdot z)cv} & \frac{1+z}{(2-2\alpha\cdot z)cs} & 0 \\ \frac{1+z}{(2-2\alpha\cdot z)cs} & \frac{-2}{(2-\alpha\cdot z)cs}+\frac{-1}{(1-\alpha\cdot z)cs} & \frac{1}{(2-\alpha\cdot z)cs} \\ 0 & \frac{1}{(2-\alpha\cdot z)cs} & \frac{-2}{cv}+\frac{-2}{(2-\alpha\cdot z)cs} \end{pmatrix}$$

$$b=\begin{pmatrix} -\frac{5}{4}u_1-\frac{1}{4}z\cdot u_2-\frac{d_1}{2}-\frac{ch_1-ch_2}{2}-\frac{ch_1}{cv}+\frac{(1-\beta\cdot z)(cp_1-z\cdot cp_2)}{(2-2\alpha\cdot z)cs}+\frac{(1-\beta\cdot z)cp_1+V}{(1-\alpha\cdot z)cv} \\ -\frac{1}{4}z\cdot u_1-\frac{7}{4}u_2-\frac{(2-\alpha\cdot z)d_1-2d_3}{4-2\alpha\cdot z}+\frac{ch_1-ch_2}{2cs}+\frac{(1-\alpha\cdot z)\left(\frac{1}{2}u_2\cdot cs-ch_2\right)+(1-\beta\cdot z)cp_2+ch_3}{(2-\alpha\cdot z)cs}-\frac{(1-\beta\cdot z)(z\cdot cp_1-cp_2)}{(2-2\alpha\cdot z)cs} \\ -\frac{3}{2}u_3+\frac{(1-\alpha\cdot z)d_3}{2-\alpha\cdot z}+\frac{cp_3-ch_3+V}{cv}+\frac{\frac{1}{2}u_3\cdot cs+cp_3+(1-\alpha\cdot z)ch_2-ch_3}{(2-\alpha\cdot z)cs} \end{pmatrix}$$

Appendix E: Proof of concavity of benefit of ports for Chapter 4

Proposition. The benefits of ports (Π_i) are concave with respect to each port charge (w_i).

Proof. The first order conditions of benefits are as follows:

$$\frac{\partial \pi_1}{\partial w_1} = -\frac{5}{4}u_1 - \frac{d_1}{2} - \frac{ch_1 - ch_2}{2cs} - \frac{ch_1}{cv} - \frac{2w_1 - w_2 - (1 - \beta \cdot z)cp_1}{(2 - 2\alpha \cdot z)cs} - \frac{2w_1 - (1 - \beta \cdot z)cp_1 - V}{(1 - \alpha \cdot z)cv}$$

$$\frac{\partial \pi_2}{\partial w_1} = -\frac{1}{4}u_2 + \frac{w_2 - (1 - \beta \cdot z)cp_2}{(2 - 2\alpha \cdot z)cs}$$

$$\frac{\partial \pi_1}{\partial w_2} = -\frac{1}{4}u_1 + \frac{w_1 - (1 - \beta \cdot z)cp_1}{(2 - 2\alpha \cdot z)cs}$$

$$\frac{\partial \pi_2}{\partial w_2} = -\frac{7}{4}u_2 - \frac{(2 - \alpha \cdot z)d_1 - 2d_3}{4 - 2\alpha \cdot z} + \frac{ch_1 - ch_2}{2cs} + \frac{w_1 - 2w_2 + (1 - \beta \cdot z)cp_2}{(2 - 2\alpha \cdot z)cs} + \frac{-2w_2 + w_3 + \frac{1}{2}(u_2 - \alpha \cdot z \cdot u_2)cs + (1 - \beta \cdot z)cp_2 - (1 - \alpha \cdot z)ch_2 + ch_3}{(2 - \alpha \cdot z)cs}$$

$$\frac{\partial \pi_3}{\partial w_3} = -\frac{3}{2}u_3 + \frac{(1 - \alpha \cdot z)d_3}{2 - \alpha \cdot z} - \frac{2w_3 - cp_3 + ch_3 - V}{cv} + \frac{w_2 - 2w_3 + \frac{1}{2}cs \cdot u_3 + cp_3 + (1 - \alpha \cdot z)ch_2 - ch_3}{(2 - \alpha \cdot z)cs}$$

The second order conditions of benefits are as follows:

$$\frac{\partial^2 \Pi_1}{\partial {w_1}^2} = \frac{\partial^2 \pi_1}{\partial {w_1}^2} + z\frac{\partial^2 \pi_2}{\partial {w_1}^2} = \frac{-1}{(1 - \alpha \cdot z)cs} + \frac{-2}{(1 - \alpha \cdot z)cv}$$

$$\frac{\partial^2 \Pi_2}{\partial {w_2}^2} = \frac{\partial^2 \pi_2}{\partial {w_2}^2} + z\frac{\partial^2 \pi_1}{\partial {w_2}^2} = \frac{-2}{(2 - \alpha \cdot z)cs} + \frac{-1}{(1 - \alpha \cdot z)cs}$$

$$\frac{\partial^2 \Pi_3}{\partial {w_3}^2} = \frac{\partial^2 \pi_3}{\partial {w_3}^2} = \frac{-2}{cv} + \frac{-2}{(2 - \alpha \cdot z)cs}$$

Since $0 \le \alpha \le 1, 0 \le z \le 1, cs > 0$, $\frac{\partial^2 \Pi_1}{\partial {w_1}^2} < 0$, $\frac{\partial^2 \Pi_2}{\partial {w_2}^2} < 0$, $\frac{\partial^2 \Pi_3}{\partial {w_3}^2} < 0$ ■

Appendix F:Hinterland area in Chapter 4

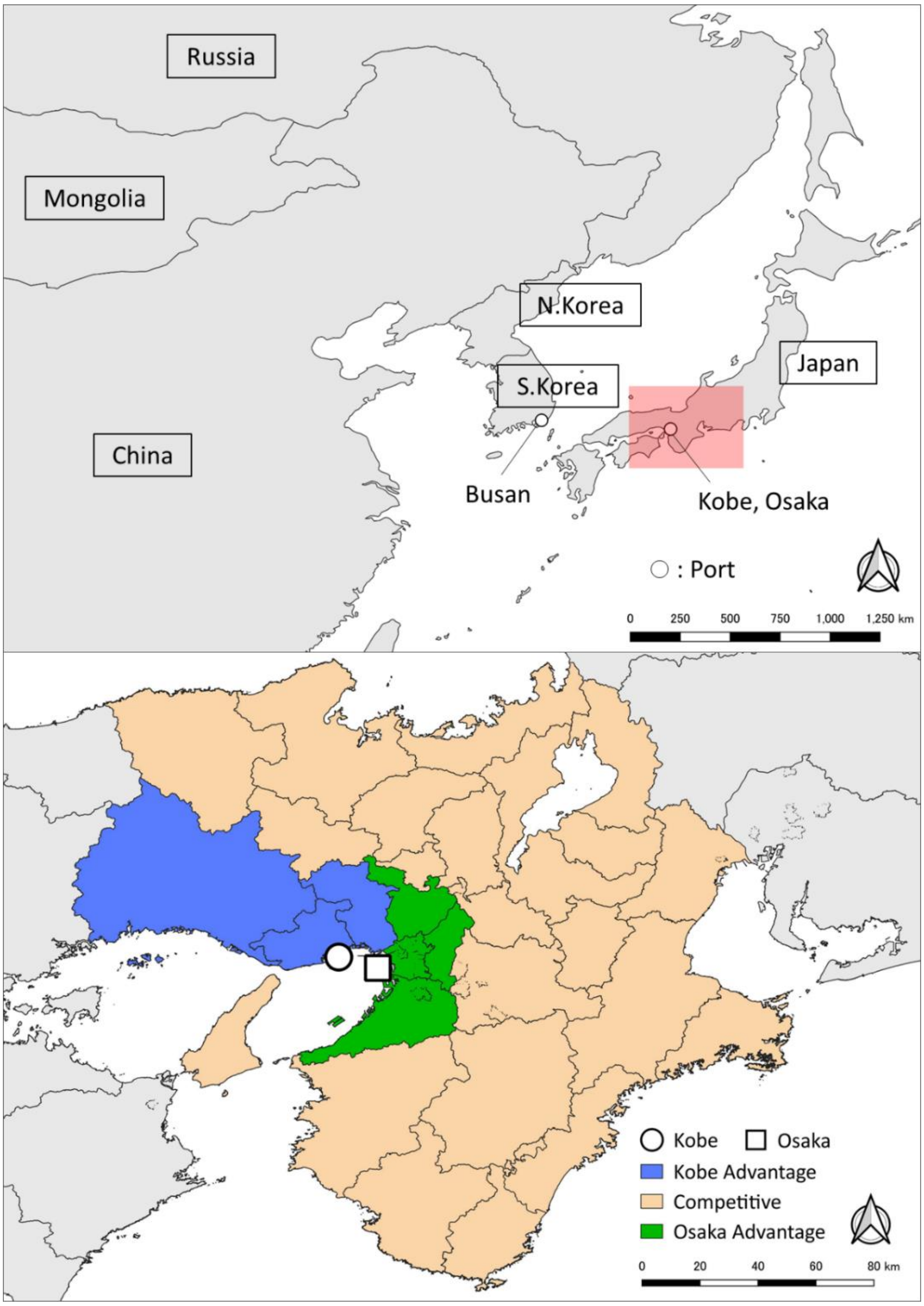


Figure A.1 Hinterland area

Kobe Advantage: Amagasaki, Harima, Kobe

Competitive: Awaji, Chunansei, Hokusei, Higashi Kishu, Iga, Iseshima, Kameoka, Kyoto, Kyoto Hokubu, Kyoto Nanbu, Nanwa, Nara, Reinan, Shingu, Sigaken Chubu, Sigaken Nanbu, Sigaken Touhokubu, Tajima, Tamba, Tanabe, Uji, Wakayama,

Osaka Advantage: Higashi Osaka, Osaka, Sakai, Toyonaka

The areas are based on MLIT (2016)

Appendix G:Illustration of solution algorithm for Chapter 4

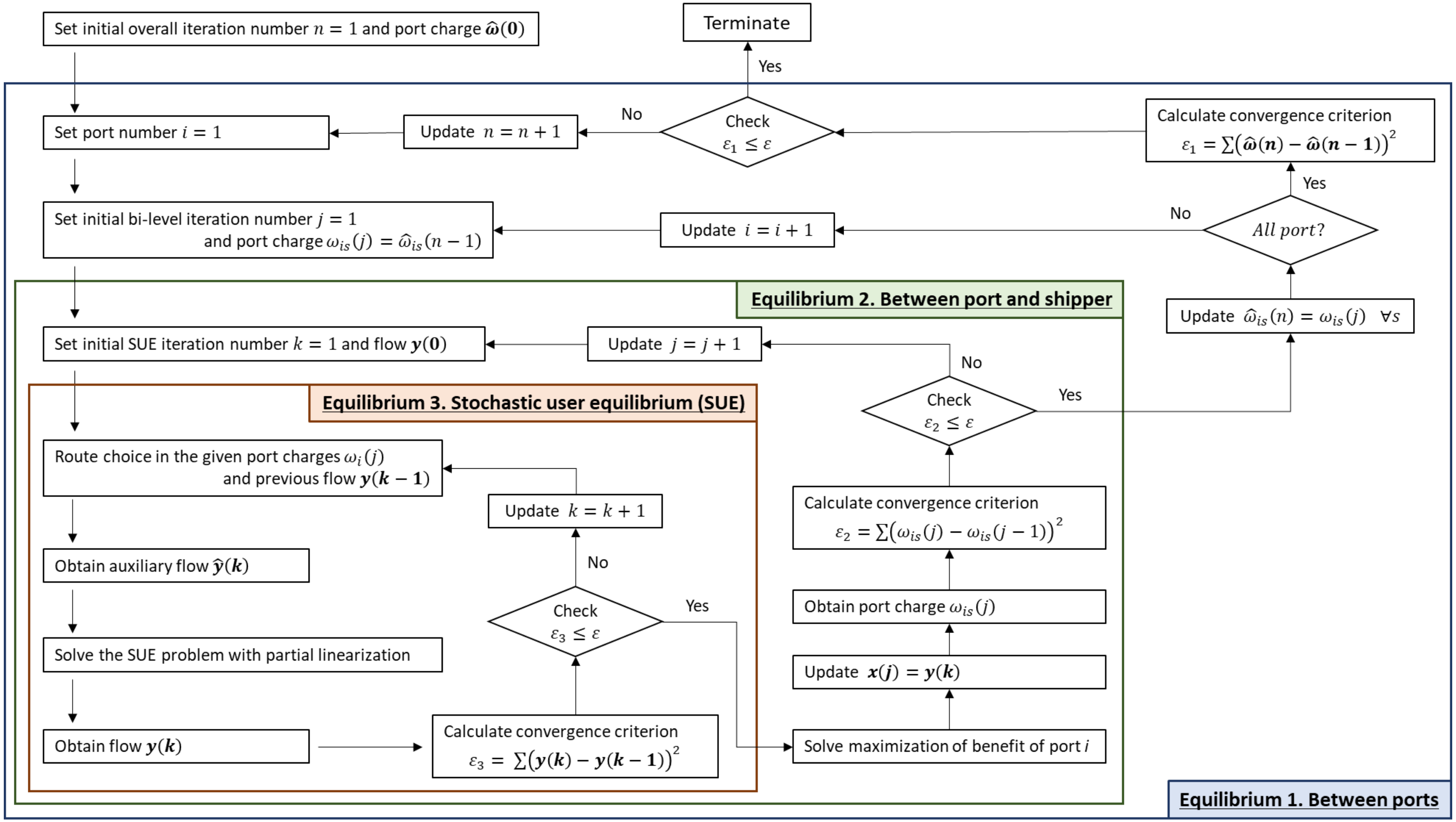


Figure A.2 Solution algorithm

Appendix H: Breakdown of input values for Chapter 4

ct_{ri} : Monetary transshipment cost [USD/TEU]

$(Monetary\ transshipment\ cost) = (Fuel\ cost) + (Capital\ cost) + (Operation\ cost)$

tt_{ri} : Shipping time in transshipment [day]

$(Shipping\ time\ in\ transshipment)$
$= (Navigation\ time) + (Waiting\ time\ at\ port\ in\ transshipment)$

$(Navigation\ time) = (Navigation\ distance)\ /\ (Navigation\ speed)$

$(Wating\ time\ at\ port\ in\ transshipment)$
$= (Loading\ Unloading\ time) + (Congestion\ time) + 0.5\ /\ (frequency)$

ch_{ri} : Monetary hinterland cost [USD/TEU]

$(Monetary\ hinterland\ cost) = (Navigtaion\ cost) \cdot (Navigtaion\ distance)$

th_{ri} : Shipping time in hinterland [day]

$(Shipping\ time\ in\ hinterland) = (Navigtaion\ distance)\ /\ (Navigtaion\ speed)$

tp_{is}: Waiting time at port [day]

$(Wating\ time\ at\ port)$
$= (Loading\ Unloading\ time) + (Congestion\ time) + 0.5\ /\ (frequency)$

cq_i : Operation cost in port [USD/TEU]

$(Opration\ cost) = (port\ management\ cost + Labor\ cost\ in\ port)/(cargo\ throughput)$

ck_i : Terminal maintenance cost [USD/TEU^2]

$(Terminal\ Maintenance\ cost) = (Capital\ cost + Maintenance\ cost)/(Port\ Capacity)^2$

kp_{is} : Assigned capacity to the cargo [TEU]

$(Assigned\ capacity\ to\ cargo)$
$= (Total\ port\ capacity) \times (cargo\ volume)/\ (Total\ cargo\ volume)$

w_{is} : Port charge [USD/TEU]

$(Port\ charge) = (port\ due) + (tonnage\ due) + (wharfage) + (pilotage) + (tug\ hire)$
$+ (terminal\ handling\ charge)$

cm_{is} : Monetary maritime cost [USD/TEU]

$(Monetary\ maritime\ cost) = (Fuel\ cost) + (Capital\ cost) + (Operation\ cost)$

tm_{is} : Shipping time in maritime transport [day]

$(Shipping\ time\ in\ maritime\ transport)$
$= (Navigation\ distance)/(Navigation\ speed)$
$+ (Time\ to\ call\ at\ other\ ports)$

Appendix I: Ports of WorldLarge in LINER-LIB for Chapter 5

Figure A.3 Location of ports in WorldLarge (black points are location of ports)

List of 201 ports in Worldlarge in LINER-LIB

Aarhus, Aberdeen, Abidjan, Acajutla, Adelaide, Aden, Agadir, Al Aqabah, Al Jubayl, Alesund, Alexandria, Algeciras, Algiers, Ambarli, Annaba, Antwerp, Apapa, Arica, Ash Shuwaykh, Ashdod, Auckland, Balboa, Baltimore, Bandar Abbas, Barcelona, Barranquilla, Beirut, Bejaia, Bergen, Bissau, Boma, Bremerhaven, Brest, Brisbane, Buenaventura, Buenos Aires, Busan, Callao, Cape Town, Casablanca, Charleston, Chennai, Chittagong, Cochin, Colombo, Conakry, Corinto, Cotonou, Da Nang, Dakar, Dalian, Damietta, Dammam, Dar es Salaam, Djibouti, Douala, Dublin, Dunkerque, Durban, Dutch Harbor, Ensenada, Esmeraldas, Felixstowe, Fort de France, Fos sur Mer, Freetown, Fremantle, Fuzhou, Gdynia, General Santos City, Genoa, Gioia Tauro, Gothenburg, Guam, Guayaquil, Haifa, Haiphong, Hakata, Hamburg, Hong Kong, Honolulu, Houston, Iquique, Itajai, Izmir, Jakarta, Jawaharlal Nehru, Jebel Ali, Jeddah, Kaliningrad, Kaohsiung, Karachi, Keelung, Kobe, Koper, Kotka, Kristiansand, La Guaira, Laem Chabang, Las Palmas, Latakia, Lazaro Cardenas, Le Havre, Leixoes, Lianyungang, Libreville, Limassol, Lobito, Lome, Long Beach, Los Angeles, Luanda, Lyttelton, Malaga, Manaus, Manila, Manzanillo, Matadi, Melbourne, Mersin, Miami, Mombasa, Monrovia, Montevideo, Montreal, Nagoya, Nelson, New Orleans, New Plymouth, New York, Noumea, Oakland, Odessa, Oran, Osaka, Papeete, Paranagua, Penang, Philadelphia, Pipavav, Piraeus, Pointe Noire, Port Chalmers, Port Elizabeth, Port Gentil, Port Klang, Port Louis, Port Qasim, Port Said, Poti, Puerto Cabello, Puerto Cortes, Puerto Deseado, Puerto Limon-MoinPuerto Madryn, Qingdao, Rauma, Rio Grande, Rotterdam, Rouen, Saigon, Salalah, Salerno, San Antonio, San Juan, Santa Cruz De Tenerife, Santos, Savannah, Seattle, Semarang, Sfax, Shanghai, Shenzhen, Shimizu, Singapore, Skikda, Southampton, St Petersburg, Stavanger, Surabaya, Suva, Sydney, Takoradi, Tangier, Tanjung Pelepas, Tarragona, Thames Haven, Thessaloniki, Tokyo, Trieste, Tunis, Valencia, Vancouver, Varna, Vigo, Vitoria, Wellington, WilmingtonNC, Xiamen, Yokohama, Zeebrugge

Appendix J: Cost function in making backbone flow procedure for Chapter 5

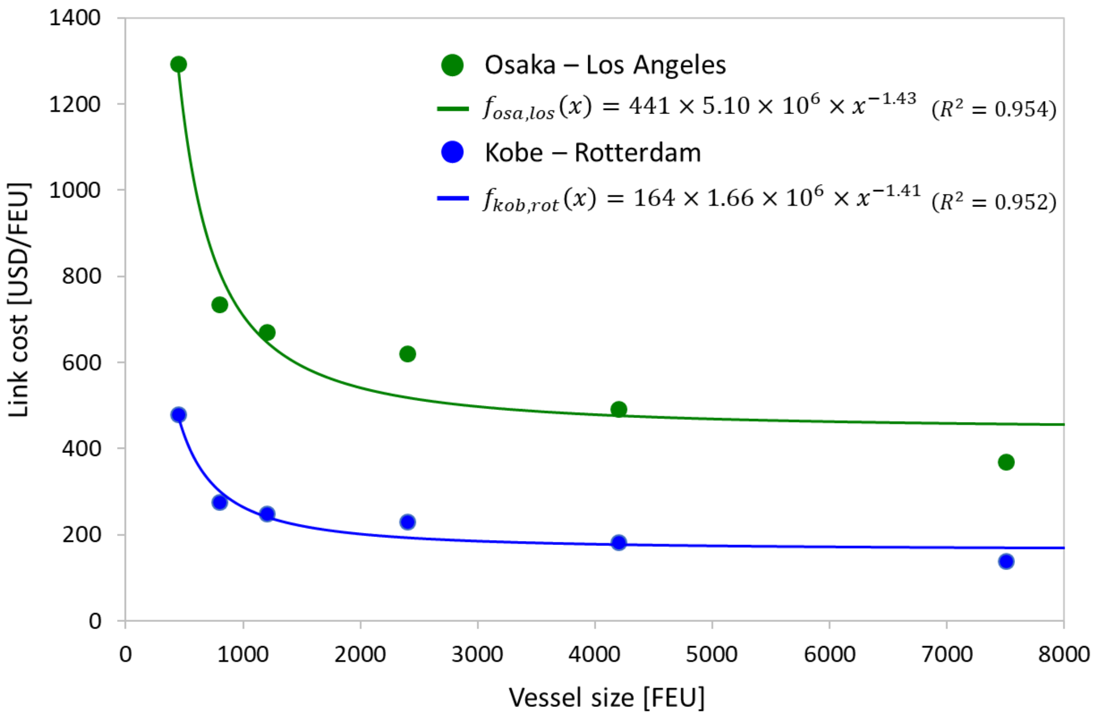


Figure A.4 Cost function in backbone flow

Appendix K: Overview of the algorithm for Chapter 5

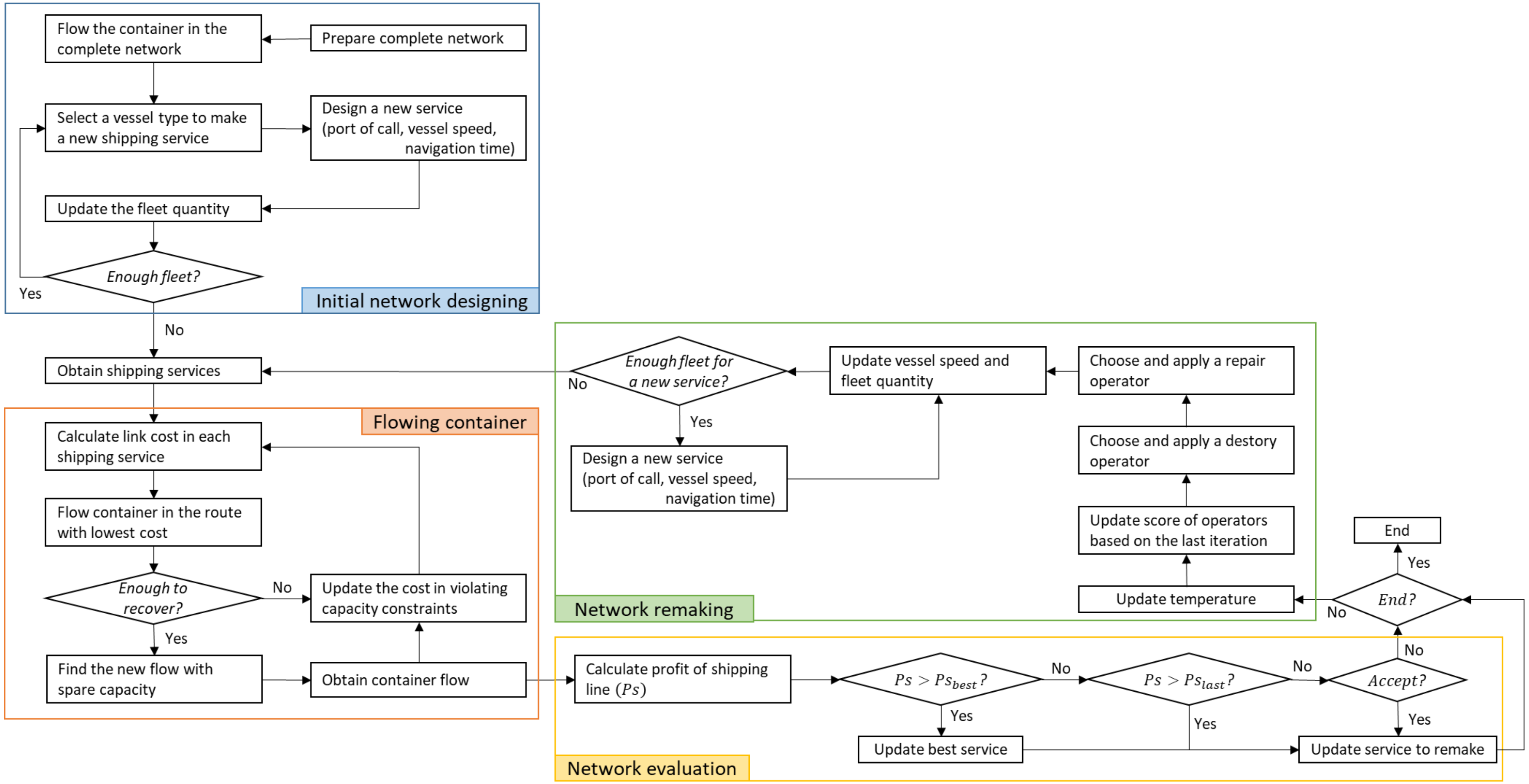
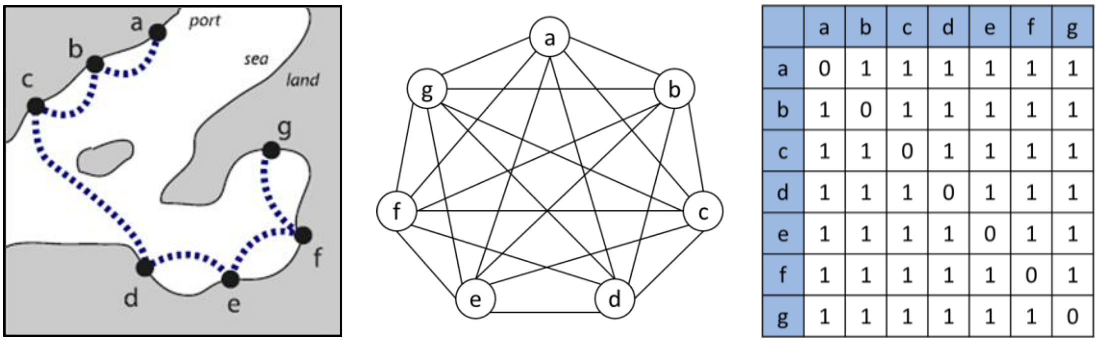


Figure A.5 Overview of the algorithm

Appendix L: Example of graph of linkages for Chapter 5



	a	b	c	d	e	f	g
a	0	1	1	1	1	1	1
b	1	0	1	1	1	1	1
c	1	1	0	1	1	1	1
d	1	1	1	0	1	1	1
e	1	1	1	1	0	1	1
f	1	1	1	1	1	0	1
g	1	1	1	1	1	1	0

(a) (b) (c)

Figure A.6 Example of graph of all linkages (a) shipping service (procedures: a,b,c,d,e,f,g,a) (b) network structure (c) adjacency matrix

Source: Ducruet (2016) modified by author

Appendix M: Example of weighted betweenness for Chapter 5

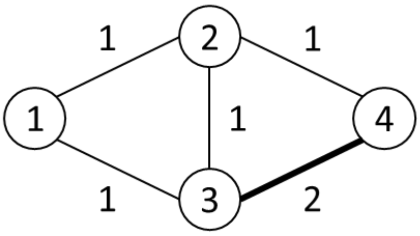


Figure A.7 Network example

Non-weighted distance: $d_{12} = 1, d_{13} = 1, d_{14} = d_{12} + d_{23} = 2$

Weighted distance: $d_{12} = 1, d_{13} = 1, d_{14} = d_{12} + d_{23} = 1 + 1/2 = 3/2$

(d_{ij} : distance between nodes *i* and *j*)

Appendix N: Measures of top-fifty ports with highest strength in base for Chapter 5

Degree increase and strength increase from base (24 ports)

Beirut, Busan, Casablanca, Charleston, Colombo, Da Nang, Dalian, Felixstowe, Gioia Tauro, Hong Kong, Jebel Ali, Kaohsiung, Keelung, Kobe, Nagoya, Osaka, Port Klang, Port Said, Shanghai, Shenzhen, Shimizu, Singapore, Yokohama, Zeebrugge

Degree increase and strength decrease from base (3 ports)

Alexandria, Ashdod, Barcelona

Degree decrease and strength increase from base (3 ports)

Bremerhavem, Los Angeles, Rotterdam

Degree decrease and strength increase from base (20 ports)

Aarhus, Agadir, Algeciras, Algiers, Annaba, Antwerp, Bejaia, Cape Town, Dammam, Fuzhou, Gothenburg, Le Havre, Manzanillo, Oran, Saigon, Southampton, Tangier, Tanjung Pelepas, WilmingtonNC, Xiamen