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Efficient inter-port cooperation considering port congestion and port charge

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ABSTRACT

This paper discusses the efficiency of cooperation among ports under congested conditions and determines an approach for strategic cooperation between ports through model analysis. We develop a bilevel optimization model based on the benefit maximization problem of port authorities and cost minimization problem of cargo carriers. We consider several port cooperation scenarios in the numerical computation. From the computation results, the following conclusions are derived: (1) when each port authority prioritizes its own profit, port cooperation in a congested port would be successful because the cooperation can be beneficial for the carrier; (2) when each port authority considers the benefit of its local customers in terms of shipping costs related to both economies of density and port congestion, port cooperation in a congested port would rarely be successful because the cooperation cannot be beneficial for the carrier and the carrier cannot support it.

1. Introduction

Attracting cargo, especially transshipment cargo, is the primary objective of the ocean freight transport industry. Following the globalization of the economy in the last two decades, international ports that serve local economies as essential gateways to the world economy are facing increased competition from potential rivals. The major ports in Japan are typical cases of this situation.

The Kobe port (henceforth referred to as Kobe) was ranked as a major container port and served as a hub/gateway in the Asia-Pacific trade market during the 1980s. However, owing to structural changes in the Asian economy,[1] Kobe lost its share of the market and floundered against rising new competitors such as the Port of Busan and Chinese ports in later years. In particular, the Port of Shenzhen in China acts as a gateway port connecting not only the southern part of China and the west coast of North America but also ASEAN countries and North America. Because of the phenomenal rise in the economic power of ASEAN countries, providing connecting services between ASEAN countries and North America is highly lucrative to the ports in both Southeast and East Asia. Therefore, the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT) announced a new approach to restore the competitiveness of major Japanese ports including Kobe (MLIT, 2018). A major scheme is to strengthen the connection to ASEAN countries by developing a transshipment port between ASEAN countries and the west coast of North America to cater to changing supply chains.

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[1] Labor-intensive industries such as intermediate goods manufacturers have moved out of Japan to neighboring countries since the mid-1980s because of high labor costs in Japan.

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Owing to rising production costs in China, mainly due to labor costs and the US–China trade war, a part of the supply chains in manufacturing industries has moved to ASEAN countries (DHL Resilience360, 2019). This is because of the improved production efficiency of the manufacturing sector in ASEAN countries. As a result, not only China–North America and China–EU trade but also ASEAN–North America and EU trade play important roles in global supply chains.

In this context, ASEAN's position in the manufacturing sector in Asia is improving, resulting in the emergence of a new trend of ocean trade routes from/to Asia. Among Pacific eastbound routes, Shanghai-based routes across the Tsugaru Strait have been the main ones. However, because of the rise of ASEAN countries, routes that avoid the Tsugaru Strait and directly travel through the Pacific Ocean have become useful as an alternative main route to reduce lead time.

In this situation, carriers can form several different trade route patterns and have more options for designing their shipping network, especially for transshipment. Therefore, several international ports located in East and Southeast Asia are facing tougher and more serious challenges. Similarly, there is fierce competition among international ports in Southern Europe in the Mediterranean Sea and in the Middle East in the Arabian Sea along the Europe–Asia route.

One possible way of survival for these ports is to cooperate with carriers or other ports to improve their productivity or profitability. Vertical cooperation (i.e., vertical integration) between terminal operators and carrier/shipping companies is a viable option and has been discussed in some studies (Van de Voorde and Vanelslander, 2008; Notteboom and Rodrigue, 2012; Álvarez-San Jaime et al., 2013). This mode of cooperation has been successfully implemented in some major ports such as the Port of Tanjung Pelepas in Malaysia.

Another method for survival is horizontal cooperation, for example, cooperation among terminal operators or cooperation among port authorities. There are some variations of horizontal cooperation. At the port level, horizontal cooperation usually refers to the cooperative relationship among terminal operators. For example, Van de Voorde and Vanelslander (2008) discussed horizontal cooperation at the port level and mergers and acquisitions (M&A) among terminal operators from a historical point of view. M&A is, of course, the most aggressive way to cooperate. Instead of M&A, a more moderate way of cooperation can be adopted. A few studies have investigated cooperative relationships among terminal operators (Song, 2003; Saeed and Larsen, 2010; Kavirathna et al., 2019) and cooperation among ports without M&A (Yap and Lam, 2004; Hwang and Chiang, 2010). However, few studies have investigated cooperative relationships in consideration of conditions such as port congestion.[2] In East Asia, many recently developed international ports that would compete with each other often have operating constraints such as port capacity or have difficulties in implementing rapid improvements owing to budget constraints. This can induce critical congestion at these ports in the near future. In regard to these issues, discussing the efficiency of port cooperation in consideration of operating constraints is meaningful in terms of actual port management and will provide productive information for devising strategies to survive in the market.

This paper aims to discuss the efficiency of cooperation among ports that have operating constraints and to determine a path for strategic cooperation between them through model analysis. We demonstrate changes in the port charge and their effects on the market, that is, market share, transition of cost, benefit to the port authority, and cost to the carrier, based on several scenarios, to change the combinations of congestion and thereby express port conditions as port operation constraints, irrespective of whether a port is congested, lightly congested, or not congested. The primary objective is to show the possibility of port cooperation in consideration of different congestion conditions using a bilevel optimization model to formulate a new port management strategy under severe competition among ports in a region.

The remainder of this paper is organized as follow. Section 2 briefly reviews related research. Section 3 describes the formulation of the bilevel optimization model, which corresponds to mathematical programming with equilibrium constraints (MPEC). Section 4 describes the numerical computations and discusses the effect of port cooperation on port authorities and carriers. Finally, Section 5 summarizes the conclusions of this study and discusses future research directions.

2. Literature review

Some early studies focused on the rise in competition among ports (Cullinane et al., 2005; Acosta et al., 2007; Lam and Yap, 2008) through empirical analysis. From a theoretical perspective, Anderson et al. (2008) proposed a fundamental analysis based on Nash equilibrium. Ishii et al. (2013) enhanced the game theoretic approach to analyze competition by deciding the port charges between Kobe and the Port of Busan. Bae et al. (2013) also analyzed the competitive situation among ports by applying the framework of a two-stage game. These theoretical game-based analyses highlighted the operational methods of port authorities and assumed demand elasticity without describing the details of the demand.

By contrast, some studies analyzed the behavior of carriers and/or shippers (Nir et al., 2003; Zhang et al., 2018) and discussed competition in consideration of the network complexity. Yang (1999) and Kuroda et al. (2005) adopted the carrier–shipper interaction approach for applying the concept of general Nash equilibrium between the behaviors of carriers and shippers to the market structure.

These studies mainly considered the competitive ocean freight transportation market where players such as carriers and port authorities compete with each other without any cooperative relationship.

Regarding the cooperative relationship among the players mentioned above, Notteboom and Rodrigue (2012) stated that global operators expand their network globally with vertical and horizontal integration in the terminal and shipping industry. They focused on the geographical trend in the container shipping industry. From an operational point of view, Venturini et al. (2017) discussed

[2] The definition of port congestion has been addressed in some recent studies (Zhen, 2016; Talley and Ng, 2016; Iris et al., 2018; Nishimura, 2020). These studies defined port congestion as occurring at a berth and yard level. We follow this definition.

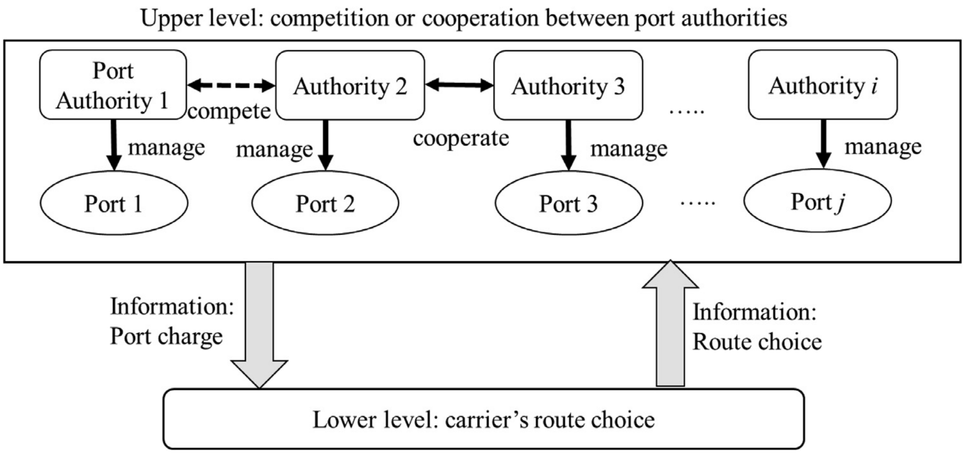

Fig. 1.. Concept of bilevel model.

vertical cooperation between carriers and operators as a berth allocation problem. Vertical integration is sometimes adopted in the market as a means for cooperation; however, its potential may be limited because such integration can be driven by global operators. By contrast, horizontal integration (i.e., horizontal cooperation) can afford more options. Hoshino (2010) presented an outlook of the situation faced by the ports in Eastern Asia and demonstrated the possibility of port cooperation among neighboring ports. Donselaar and Kolkman (2010) discussed the effect of port cooperation and the role of government in enhancing port cooperation. They concluded that port cooperation can counteract the undesirable side effects of competition and provide the opportunity to improve efficiency. Saeed and Larsen (2010) discussed the effect of cooperation among terminals in Karachi, Pakistan, by applying a two-stage game.

Another aspect of cooperative relationships is known as "coopetition," which was theoretically described by Song (2003) and applied to the container shipping industry.[3] Lin and Huang (2013) discussed coopetition at the carrier level, and Kavirathna et al. (2019) developed the coopetition-in-a-port model and discussed the features of both competitive and cooperative relationships among terminal operators in the port.

Most studies on cooperation in a port concluded that the cooperative relationship among terminals can reduce the negative impact of competition and improve the efficiency (or productivity) of ports (or terminals). Thus, the cooperation among terminals located in the same port or neighboring ports has been discussed in some of the studies mentioned above; however, inter-port cooperation considering shipping network configuration has rarely been reported. Naturally, when the relationship among ports is changed, the behavior of the stakeholders can change. In particular, liner shipping companies redesign their shipping plans and provide new optimal shipping routes in such a scenario. This must be important to every port authority that wants to invite more cargo and/or improve its profitability. Furthermore, most studies dealing with cooperative relationships among ports and/or terminals did not consider the operating constraints of ports such as capacity, which is crucial for enhancing port productivity. These elements should be treated when we discuss realistic strategic port cooperation.

Our research contribution is that we discuss the efficiency of inter-port cooperation by considering the behavior of carriers (shown as demand at a port) explicitly, which has not been performed in previous studies. Our research adopts a theoretical approach but describes the behavior of carriers more realistically by introducing appropriate operating constraints.

3. Bilevel optimization model

3.1. Outline

In this analysis, we propose a bilevel network design model. At the upper level, we consider the competition and/or cooperation among port authorities that aim to maximize their benefits. This level comprises the profit of the port authority and reduction in transport costs of local shippers. At the lower level, we consider the behavior of the cargo carrier. To avoid complexity, we assume a monopolistic carrier in the market.

Fig. 1 shows a schematic of the model. The relationship between port authorities is set in the upper level. There are competitive or cooperative relationships between authorities, which manage the port charges. For example, port authorities 2 and 3 have a cooperative relationship in Fig. 1; that is, these two authorities function as one authority, and they decide the port charges at ports 2 and 3 together. By contrast, port authority 1 does not cooperate with others, and therefore, it decides the port charges at port 1 alone. Each authority can obtain information about a competitor's decision. The carrier decides its shipping routes (lower level) once it obtains information regarding the port charges at each port. This is because the carrier cannot compare the route status without

[3] The idea of "coopetition" is recognized as "partial cooperation" or "selective cooperation."

information regarding the port charges. Based on the carrier's behavior, the authorities modify the port charges. Finally, this system will reach a steady state, that is, an equilibrium condition.

3.2. Carrier behavior

Consider the case where a monopolistic cargo carrier exists in the market. It carries cargo from an origin (denoted as r) to a destination (denoted as s). The origin–destination (OD) cargo flow is assumed to be predetermined and fixed because all transportation charges have been paid before departure. Therefore, the monopolistic cargo carrier designs a desirable transport (shipping) network. Because cost minimization for the carrier's behavior is often assumed in cargo transport analysis (Smilowitz et al., 2003; Karlaftis et al., 2009; Apivatanagul and Regan, 2010; Wang et al., 2013), we follow this assumption. As our model assumes a monopolistic carrier, the model differs from other bilevel models (Takebayashi, 2013, 2016; Takebayashi and Onishi, 2018) that assumed an oligopolistic market considering the users' route choice in a structure.

The control variable of the cargo carrier is a path flow on path k of the rs OD pair, x_k^{rs}. It considers a path-dependent cost, c_k^{rs}, and designs its desirable network. The carrier pays port charges $\boldsymbol{w}$ to the port authorities or receives incentives from the authorities. Therefore, its cost minimization problem under the given charge (or incentive) policy is formulated as

$$\min_{\mathbf{x}} \; Z(\mathbf{x}|\mathbf{w}) = \sum_{r\in\Omega^r}\sum_{s\in\Omega^s}\sum_{k\in K^{rs}} \{x_k^{rs}(c_k^{rs} + \sum_{h\in H} w_h \delta_h^{rsk})\}, \tag{1}$$

subject to

$$\sum_{k\in K^{rs}} x_k^{rs} = X^{rs}, \text{ for } \forall r \in \Omega^r \text{ and } \forall s \in \Omega^s, \tag{2}$$

$$x_k^{rs} \geq 0, \text{ for } \forall k \in K^{rs}, \forall r \in \Omega^r, \text{ and } \forall s \in \Omega^s, \tag{3}$$

where $\mathbf{x} = \{x_k^{rs}\}$; X^{rs} denotes the total cargo flow from r to s; Ω^r and Ω^s denote sets of origins and destinations, respectively; K^{rs} denotes a set of paths in the rs OD pair; and H denotes a set of ports.

Objective function (1) is composed of the transport cost of each path and charges (or incentives) from the authorities of port h, w_h. The path-dependent unit cost, c_k^{rs}, is composed of a link-flow-dependent cost, c_l, and a port congestion cost, c_h. Let I be a set of links. Therefore, the path-dependent cost is formulated as

$$c_k^{rs} = \sum_{l\in I} c_l \delta_l^{rsk} + \sum_{h\in H} c_h \delta_h^{rsk}, \text{ for } \forall k \in K^{rs}, \forall r \in \Omega^r, \text{ and } \forall s \in \Omega^s. \tag{4}$$

The first term on the right-hand side of Eq. (4) is the link-flow-dependent cost, and the second term is the congestion cost at port h. δ_l^{rsk} and δ_h^{rsk} are binomial variables. δ_l^{rsk} (δ_h^{rsk}) takes a value of 1 when link l (port h) is used on path k of rs; otherwise, it takes a value of 0. Regarding c_l, assuming economies of density, when the link flow $x_l = \sum_{r\in\Omega^r}\sum_{s\in\Omega^s}\sum_{k\in K^{rs}} x_k^{rs}\delta_l^{rsk}$ increases, the marginal cost decreases. Therefore, c_l satisfies the following condition:

$$dc_l/dx_l > 0 \text{ and } d^2c_l/dx_l{}^2 < 0. \tag{5}$$

We also assume that the port congestion cost increases with the cargo throughput at port h, $x_h = \sum_r\sum_s\sum_k x_k^{rs}\delta_h^{rsk}$. Then, we assume a common congestion cost structure as follows:

$$dc_h/dx_h > 0 \text{ and } d^2c_h/dx_h{}^2 > 0. \tag{6}$$

Constraint (2) represents OD flow conservation, and constraint (3) is a nonnegative constraint on the path flow.

3.3. Port authorities

We assume that the port authorities compete with each other in the seaborne cargo transportation market. Each authority controls its port charge (or incentive) applied to the carrier, w_h, and maximizes its benefits. In this study, we consider the local users' benefits, that is, the total transportation cost of local shippers, as well as the authority's profit from the port charges, w_h. Thus, the benefits of the port authority n can be regarded as a kind of welfare. Therefore, we specify that the port authority n aims to maximize its welfare. Now, we set up scenarios of port cooperation, that is, a consortium, denoted as $\boldsymbol{\gamma}$.

Under this situation, the cost minimization problem of the port authority n under the scenario $\boldsymbol{\gamma}$is formulated as

$$\max_{\mathbf{w}} \; \pi^n(\mathbf{w}|\boldsymbol{\gamma}) = \sum_{h\in H^n} x_h w_h - \alpha \sum_{h\in H^n}\sum_{r\in\Omega^r}\sum_{s\in\Omega^s}\sum_{k\in K^{rs}} C_k^{rs} x_k^{rs} \delta_{h,0}^{rsk}, \tag{7}$$

subject to

$$x_k^{rs} = \arg\{\min \; Z(\mathbf{x}|\mathbf{w})\}, \tag{8}$$

where $\mathbf{w} = \{w_h\}$, $x_h = \sum_{r\in\Omega^r}\sum_{s\in\Omega^s}\sum_{k\in K^{rs}} x_k^{rs}\delta_h^{rsk}$ and $C_k^{rs} = c_k^{rs} + \sum_{h\in H} w_h$.

The objective function (7) is composed of the profit, link-flow-dependent costs, port charge, and port congestion costs charged to local shippers. These profits and costs are combined by a balancing parameter α. When α increases, the port authority considers the local shipper's cost to be more important. When α decreases, the authority becomes more sensitive to its own profit. This model setting can be seen in other studies dealing with the behavior of the public (or semipublic) sector (Zhang and Czerny, 2012; Czerny and Zhang, 2015). Regarding port management, we assume that the authority n can manage a multiple port system if it cooperates with other ports. A set of ports operated by the authority n is defined as H^n. $\delta_{h,0}^{rsk}$ is a binomial variable that takes a value of 1 if r or s is the hinterland of port h; otherwise, it takes a value of 0.

Constraint (8) is an optimal network design constraint set by the carrier and functions as an equilibrium constraint. Therefore, it is proposed as a solution to the carrier optimization problem discussed in Section 3.2.

3.4. Solution procedure

The proposed bilevel model entails an optimization problem with an optimal behavior constraint, which can be regarded as a generalized Nash equilibrium problem (Harker, 1991; Hong and Harker, 1992; Zhou et al., 2005). Following Harker's study, the overall system of the target problem is defined as the following variational inequality problem:

$$\sum_{n\in N}\left\{\sum_{h\in H^n}\nabla_{w_h}\pi^n(\tilde{w}_h|\boldsymbol{\gamma})(w_h-\tilde{w}_h)\right\}\leq 0 \tag{9}$$

subject to constraint (8), where $\tilde{w}_h$ denotes an optimal port charge at port h.

This optimal system corresponds to traditional MPEC considering a user equilibrium situation at a lower level (Yang, 1995, 1997; Ng et al., 2010). In the carrier model, the shipping cost c_k^{rs} can be rewritten as a combination of link costs, and the port congestion cost can be regarded as the cost appearing in the hyperlink h. Because c_l and w_h are functions of the link flow and cargo throughput, respectively, the objective function (1) can be rewritten as follows:

$$\min_{\mathbf{x}} Z(\mathbf{x}|\mathbf{w})=\sum_{r\in\Omega^r}\sum_{s\in\Omega^s}\sum_{k\in K^{rs}}\left[x_k^{rs}\left\{\sum_{l\in I}c_l\left(x_l\right)\delta_l^{rsk}+\sum_{h\in H}\left(c_h+w_h\left(x_h\right)\right)\delta_h^{rsk}\right\}\right]. \tag{10}$$

This formulation means that the carrier model in this study is formed as an optimal flow allocation problem (Ng and Waller, 2009) that can be solved by the solution method for the user equilibrium allocation problem. Therefore, we can adopt a sensitivity analysis that is commonly applied to solve this type of MPEC (Yang, 1995, 1997). When obtaining the Nash equilibrium of the competition among port authorities, the method of successive averages (MSA) can be adopted (Zhou et al., 2005).

The overall algorithm using heuristics can be shown as follows.

[Algorithm]

STEP 0: Initialize the iteration number for overall loop $\theta_a = 0$. Initial solutions are given as $\mathbf{w}(0) = \{w_h(0)\}$

STEP 1: Update the iteration number $\theta_a = \theta_a + 1$.

STEP 2: Solve the upper-level problem.

STEP 2.0: Initialize the authority's number $n = 1$ and the corresponding iteration number $i = 0$.

STEP 2.1: Solve the lower problem for obtaining x_k^{rs} via the Frank–Wolfe algorithm with given w_h. When port h is operated by authority n, the value is given as w_h^i.

STEP 2.2: Calculate $\nabla_{w_h}\pi^n(w_h|\boldsymbol{\gamma})$ and obtain the auxiliary solution $\hat{w}_h^i$ of problem (7). Determine the step size μ for obtaining the next solution $\mathbf{w}^i = \mathbf{w}^i + \mu(\hat{\mathbf{w}} - \mathbf{w}^i)$, where $\mu \in (0, 1)$ and $\mathbf{w}^i = \{w_h(i)\}$.

STEP 2.3: If μ is larger than the preset convergence criterion, update $i = i + 1$ and then return to STEP 2.1. Otherwise, go to STEP 2.4.

STEP 2.4: Save $w_h(i)$ as $w_h(\theta_a) = w_h(\theta_a) + \mu_2(w_h(\theta_a) - w_h(i))$, where step size $\mu_2 = 1/(\theta_a + 1)$. If the behaviors of all authorities are calculated, go to STEP 3. Otherwise, update $n = n + 1$, replace w_h as $w_h = w_h(\theta_a - 1)$, and return to STEP 2.1.

STEP 3: If $\sum_h \{w_h(\theta_a) - w_h(\theta_a - 1)\}^2 \leq \varepsilon$, the computation stops. ε is a preset convergence criterion. Otherwise, return to STEP 1.

Regarding STEP 2.2, $\nabla_{w_h}\pi^n(w_h|\boldsymbol{\gamma})$ can be obtained using heuristics. Tobin and Friesz (1988) proposed a derivative-based approach for sensitivity analysis. Following their approach, the estimated link flow derivative (and cargo flow at port h) $\nabla\mathbf{x_l} = \{dx_l/dw_h\}$ is given as

$$\nabla_{w_h}\mathbf{x_l} = -A_u D\left[I-\left[B_u{}^T\left[B_u D B_u\right]^{-1}B_u{}^T\right]^{-1}B_u D\right]A_u{}^T\nabla C(\mathbf{x_l}^*).$$

A_u: a link-path incidence matrix whose path k' (sequentially renumbered) is used (path flow is positive) in the rs OD pair (sequentially renumbered) based on the information of δ_l^{rsk}.

B_u: an OD pair-path incidence matrix whose path k' has positive flow in the rs OD pair.

$D = [A_u{}^T\nabla C(\mathbf{x_l}^*)A_u]^{-1}$, where $\nabla C(\mathbf{x_l}^*)$ is the derivative of the link cost (and port congestion cost) with respect to link flow.

I: An identity matrix of appropriate dimension.

4. Simulation and discussion

4.1. Assumptions and conditions

Before starting the computation, we make the following assumptions for the simulations.

(i) The OD flow is predetermined and fixed.

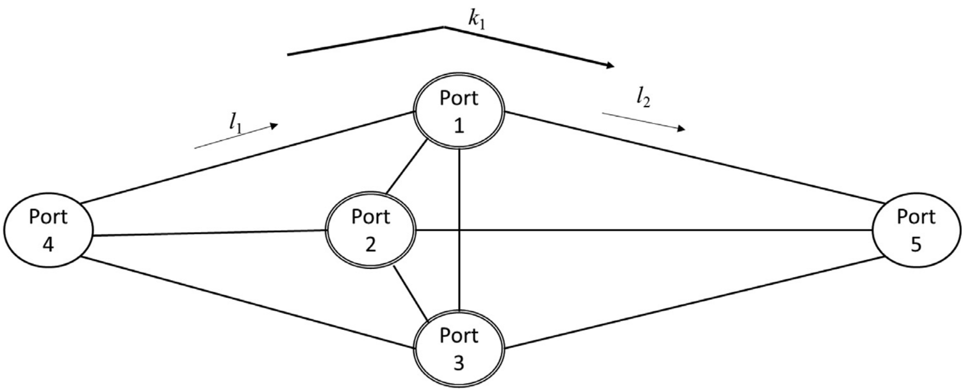

Fig. 2.. Illustration of network.
Note: Each port also works as an origin and a destination. The example of the relationship between paths and links is described as follows. The path k_1 from the origin (Port 4) to the destination (Port 5) comprises link l_1 (from Port 4 to Port 1) and link l_2 (from Port 1 to Port 5).
Note 1: "Type C: main" implies that the number of type C ports is greater than or equal to two; "Type C: one" implies that there is one type C port in the combination; and "Type C: none" implies that there is no type C port in the combination.
Note 2: The vertical axis represents the port charge.

Table 1.
OD flow and line haul distance.

	Port 1	Port 2	Port 3	Port 4	Port 5
Port 1	0	0 [30]	0 [30]	3000 [140]	3000 [80]
Port 2	0 [30]	0	0 [30]	3000 [140]	3000 [80]
Port 3	0 [30]	0 [30]	0	3000 [140]	3000 [80]
Port 4	3000 [140]	3000 [140]	3000 [140]	0	3000
Port 5	3000 [80]	3000 [80]	3000 [80]	3000	0

Note: Values in square brackets indicate the distance.

(ii) The costs related to the feeder services from/to the hinterland are negligible.
(iii) The shape of the transport network is predetermined and fixed.
(iv) The transport costs for a link have economies of density.

Assumption (i) implies that the carrier must carry all cargo for which the transportation charges are already paid. Assumptions (ii) and (iii) focus on the structure of forming the gateway ports. Assumption (iv) reflects the commonly accepted feature of transport (Zhang and Czerny, 2012).

In the computation, we have five OD zones/ports: ports 1, 2, and 3 are located close to each other, whereas ports 4 and 5 are far from ports 1, 2, and 3. The network is illustrated in Fig. 2.

The carrier does not operate directly between ports 4 and 5 because it requires long-haul transportation. Therefore, the carrier must use connecting services. The OD flow and line haul distance are listed in Table 1.

Considering the economies of density given by Eq. (5) and the congestion cost at port h given by Eq. (6), we simply assume the following formulas:

$$c_l = \bar{c}_l d_l (x_l)^{\beta},\ 0 < \beta < 1, \tag{11}$$

$$c_h = \bar{c}_h (x_h / V_h)^{\tau},\ 1 < \tau, \tag{12}$$

where $\bar{c}_l$ is the unit transport cost on link l, d_l is the flight distance of link l, and $\bar{c}_h$ is the basic cost of congestion at port h. For instance, we set $\bar{c}_l = 5$ and $\bar{c}_h = 10$, which are constant for each link and each port, respectively. V_h is an index of operational efficiency reflecting the capacity at port h. We set $\beta = 0.7$ and $\tau = 1.05$. These values are artificially determined because it is difficult to estimate them in the real market. Each initial port charge was set to 3.

As we attempt to discuss the effect of port congestion as an incentive for port cooperation, we set different levels of efficiency as $V_h = 500$ (type C: congested), $V_h = 5000$ (type M: lightly congested), and $V_h = 20{,}000$ (type N: not congested). These are not observed values but are assigned for an easy understanding of the effect of congestion. For example, the type C port has a much stronger effect than the type M port when each port handles the same amount of cargo. Finally, the benefit-balancing parameter α

Table 2.
Scenarios.

No.	Port 1, Port 2, Port 3	No.	Port 1, Port 2, Port 3	No.	Port 1, Port 2, Port 3
S-1	C, C, C	S-10	C*,M*, M	S-19	M, M, M
S-2	C*, C*, C	S-11	C, M*, M*	S-20	M*, M*, M
S-3	C, C, M	S-12	C, M, N	S-21	M, M, N
S-4	C*, C*, M	S-13	C*, M*, N	S-22	M*, M*, N
S-5	C*, C, M*	S-14	C, M*, N*	S-23	M*, M, N*
S-6	C, C, N	S-15	C*, M, N*	S-24	M, N, N
S-7	C*, C*,N	S-16	C, N, N	S-25	M*, N*, N
S-8	C*, C, N*	S-17	C*, N*, N	S-26	N, N, N
S-9	C, M, M	S-18	C, N*, N*	S-27	N*, N*, N

Note 1: C denotes “congested,” M denotes “lightly congested,” and N denotes “no congestion.”
Note 2: “*” indicates that the port operates in cooperation with other ports.

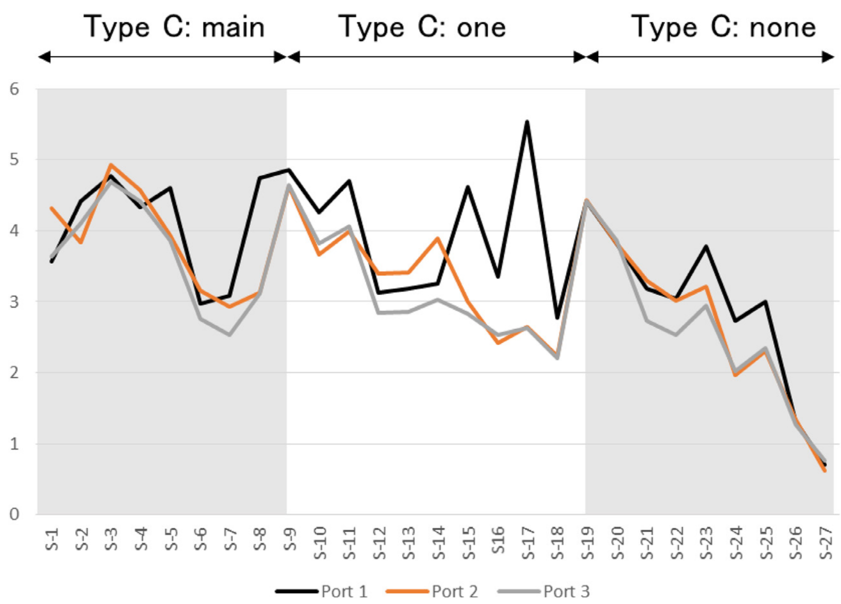

Fig. 3.. Port charge (Case-COM)
Note 1: “Type C: main” implies that the number of type C ports is greater than or equal to two; “Type C: one” implies that there is one type C port in the combination; and “Type C: none” implies that there is no type C port in the combination.
Note 2: The vertical axis represents the port charge.

of the port authorities is assumed to be constant among them. This assumption is set to avoid excessive complexity of the model behavior.

4.2. Computation results and discussion

4.2.1. Summary of results

We performed computations with several combinations of parameters. We show some typical results that are suitable for discussing the policy implications of port cooperation. In this section, we show the results of Case-COM ($\alpha = 1.2$: commercial (emphasis on the improvement of profit)) and Case-PUB ($\alpha = 1.4$: public (emphasis on the welfare of local customers)). The scenarios are listed in Table 2. Because the conditions of ports 1, 2, and 3 are identical, we should discuss the results of 27 combinations.

The results for port charges are shown in Fig. 3 (Case-COM) and Fig. 4 (Case-PUB). It is obvious that each port authority sets a higher charge when the congestion is serious (combinations of “Type C: main” and “Type C: one”). A comparison of Figs. 3 and 4 shows that the charge in Case-PUB is lower than that in Case-COM, suggesting that the port authority that regards the welfare of local customers (shipping cost) as more important than improving its profit tends to set a lower charge. Regarding the noncooperation scenarios, when port 3 is classified as type N, it always sets the lowest charge in Case-COM. By contrast, in most scenarios in Case-PUB, when port 3 is classified as type M or type N, it sets the lowest charge. These results show that the less congested port can have an incentive to set the lowest price for inviting cargo. We can confirm this suggestion when considering the market share (see Figs. 5

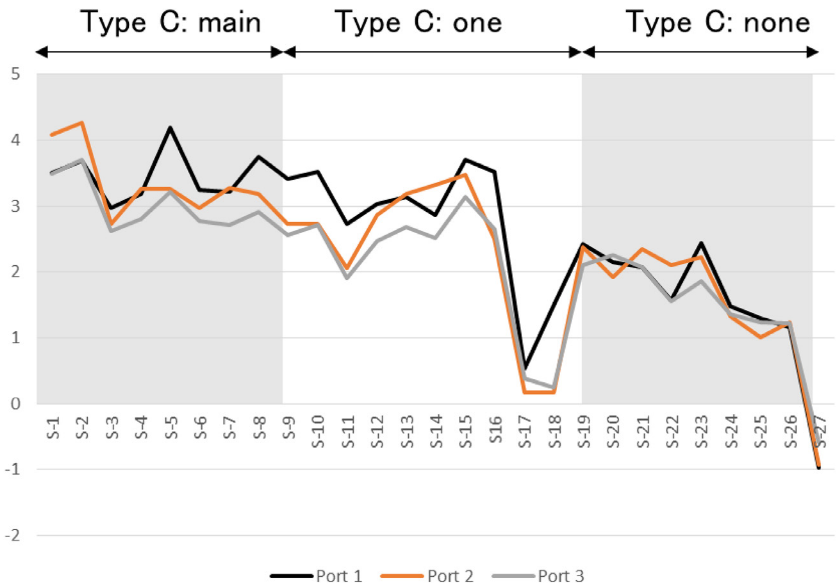

Fig. 4.. Port charge (Case-PUB).

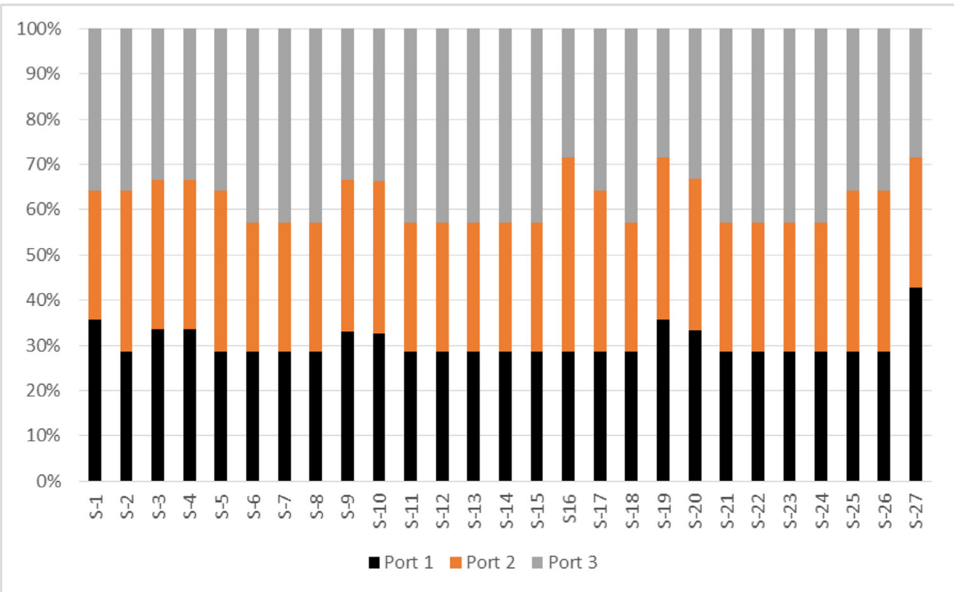

Fig. 5.. Market share (Case-COM).

and 6). When port 3 is classified as type M or type N and other ports are more congested, it occupies a major share of the market, except for S-6 in Case-PUB.

However, port cooperation can affect this market share and the charging strategy. In Case-COM, the combination (M, M, M) and the combination (N, N, N) cause lower charges through cooperation, whereas the combination (C, C, C) causes a higher charge. The same tendency can be found in Case-PUB. This tendency can be derived from the intensity of competition among the ports. When all ports are congested, port cooperation can induce an oligopolistic situation; therefore, the cooperating ports and their competitors restrain the competition and raise charges to improve their profits. By contrast, when all ports are not very congested (i.e., type M and N ports), port cooperation can promote competition, and consequently, the ports under cooperation reduce charges for inviting cargo. We can confirm this tendency in cases S-19 to S-27.

An interesting effect of port cooperation appears when considering the combination of all types (S-12 to S-15): A type C port under cooperation raises its charges, although the behavior of its partner ports differs according to their type. Specifically, a type M partner port raises its charge whereas a type N partner port reduces its charge. These contradictory actions can be attributed to the

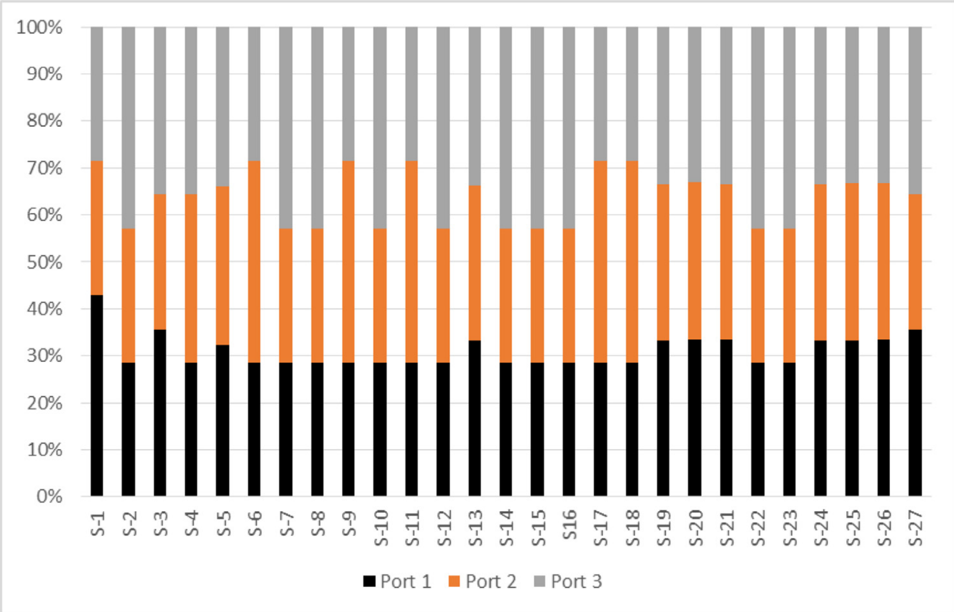

Fig. 6.. Market share (Case-PUB).

difference in sensitivity to congestion. Although the cooperating ports can improve their profits owing to charge configuration, there is a possibility of a substantial increase in congestion. Cooperation with a type M port can result in increased sensitivity to congestion than cooperation with a type N port, and thus, the cooperating ports can raise their charges. As competitors do not have any reason to reduce their charge, they respond by following their competitor's action. Furthermore, if the type C port operates on a stand-alone basis, it raises its charge to counter port cooperation. S-16 and S-18 are special cases that show the contradictory reactions. In Case-COM with cooperation between type C and type N ports, charges are raised whereas competitors reduce their charges. However, port cooperation between type N ports reduces the charge at each port. In Case-PUB, each pattern of port cooperation reduces the charge at each port. These results suggest that the number of type N ports affects the intensity of competition because the effect of congestion is diminished. If each port has a small impact on port congestion and each port authority prioritizes the benefit of local shippers (S-27 in Case-PUB), the port charge can take a negative value, implying that the port authority gives the carrier an incentive to attract more cargo.

The market share depicted in Figs. 5 and 6 indicates that a type N port can invite transshipment cargo regardless of whether the mode of cooperation is Case-COM or not. By contrast, in Case-PUB, the dominance of a type N port is sometimes eroded by the cooperation among competitors. This suggests that the gateway function becomes sensitive to cooperation when the port authorities consider their customers' benefits as more important. Type C ports rarely function as transshipment ports because of heavy congestion. Thus, a possible incentive for the authority of a type C port to cooperate with the other ports is an opportunity to improve its benefits.

Figs. 7 and 8 show the comparison of costs obtained from the objective function for the port authority. The results show that all values are negative. This means that the local customer's cost is much larger than the port authority's profit. In our model, each port authority is assumed to consider the local customer's cost reduction and its own profit. By contrast, the carrier is sensitive to port congestion when it chooses a transshipment port. The main part of the port authority's profit depends on the volume of transshipment cargo, and therefore, each port authority determines the port charge considering the balance between the movement of local cargo and the port congestion.[4] Therefore, we can understand the following: when the port authorities prioritize public benefits, they set lower charges for local customers; when the congestion level decreases, they reduce the charges to invite more transshipment cargo to improve their profits.

When each port is classified as the same type (S-1, S-2, S-19, S-20, S-26, and S-27), the costs of the ports shown in Figs. 7 and 8 decrease owing to cooperation, except for S-27 of Case-COM, where the cost increases slightly. In other cases, the total cost of cooperating ports increases (S-11, S-13, S-17, S-23, and S-25 of Case-COM; S-4, S-8, S-13, S-14, and S-17 of Case-PUB). In Case-COM, when the number of type C ports is two or more, the total cost is reduced in every combination, and therefore, these authorities have an incentive to cooperate for cost reduction. However, when type M and N ports are mixed, the effect of cost reduction by cooperation

[4] Raising the port charge has two effects—increased profit and reduced port congestion. These effects mainly influence transshipment cargo allocation. In terms of transshipment cargo allocation, the carrier's behavior is assumed to have an optimum including the user equilibrium condition: this traffic allocation is sometimes very sensitive to network conditions such as congestion. Thus, the carrier's sensitivity can drastically change the port charge configuration within a narrow range of α.

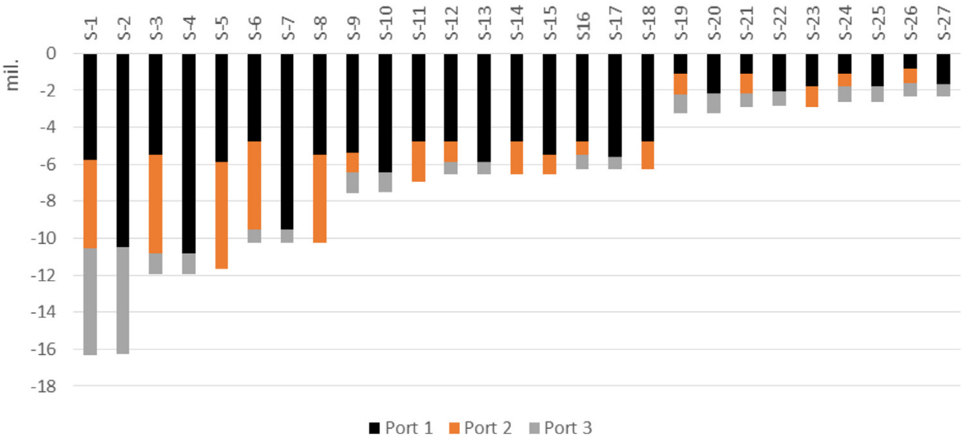

Fig. 7.. Transition of cost (Case-COM).

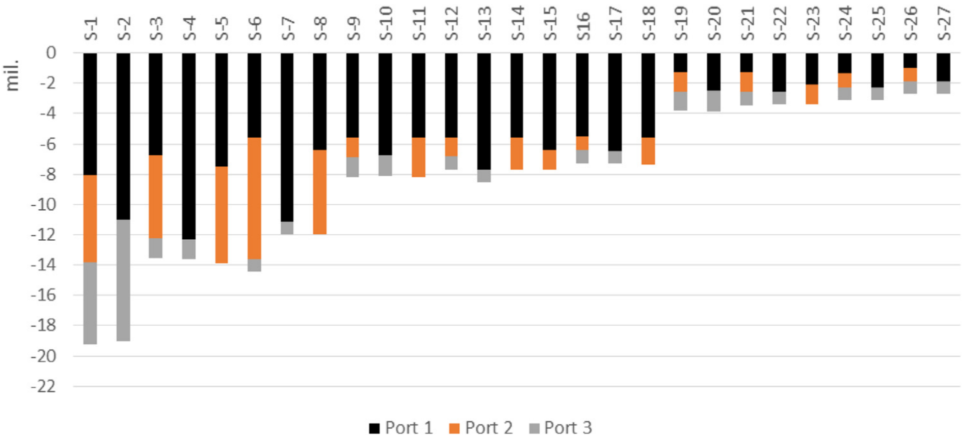

Fig. 8.. Transition of cost (Case-PUB).

sometimes varies according to the circumstances. By contrast, cooperation with a type C port rarely reduces the cost in Case-PUB. This contradictory result is attributed to the different objectives of each authority, that is, COM or PUB.

Carrier transport costs are also affected by port cooperation (see Fig. 9). In Case-COM, the cost increases in S-8, S-13, S-14, S-15, S-17, S-20, S-23, and S-25. In Case-PUB, the cost increases in S-2, S-4, S-5, S-7, S-8, S-10, S-13, S-14, and S-15. Basically, the carrier is negatively affected by the cooperation between ports, including type N in Case-COM, whereas the existence of type C appears to be a key factor in increasing the cost in Case-PUB. Thus, the carrier can show different preferences in port cooperation when the objectives of the ports are different.

4.2.2. Discussion

Based on the results reported in the previous section, we can summarize the findings as follows.

1) Each port authority sets a higher charge when the congestion is high.
2) A port authority that considers customer welfare as more important than its profit tends to set a lower charge.
3) In cases of an emphasis on improved profits, a noncongested port can invite transshipment cargos under cooperation. However, in cases of an emphasis on the welfare of local customers, the dominance of the noncongested port is sometimes impaired by the cooperation among its competitors.
4) In cases of an emphasis on improved profits, when the number of congested ports is two or more, each combination reduces the total cost. Therefore, cost reduction is an incentive for collaboration. However, the cost reduction effect due to cooperation may differ depending on the combination of the number of lightly congested and noncongested ports. In cases of an emphasis on the welfare of local customers, cooperation with a congested port rarely results in cost reduction.
5) The carrier is negatively affected by cooperation, including by a noncongested port, in cases of an emphasis on improved profits. Further, the existence of various types of ports increases the cost in cases of an emphasis on the welfare of local customers.

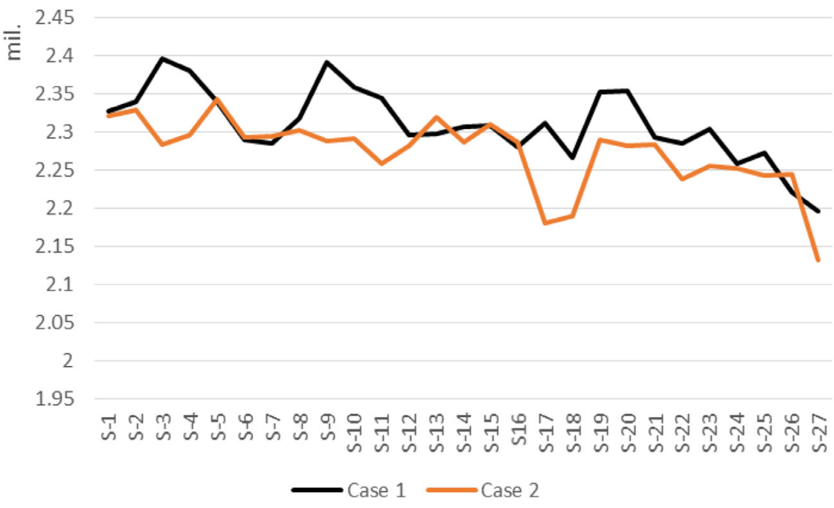

Fig. 9.. Carrier's cost.

Table 3
Summary of results (Case-COM and Case-PUB).

	Case-COM		Case-PUB	
	Port authority's benefit	Carrier's cost	Port authority's benefit	Carrier's cost
S-1	–	–	–	–
S-2	O	X	O	X
S-3	–	–	–	–
S-4	O	O	X	X
S-5	O	O	O	X
S-6	–	–	–	–
S-7	O	O	O	X
S-8	O	X	X	X
S-9	–	–	–	–
S-10	O	O	O	X
S-11	X	O	O	O
S-12	–	–	–	–
S-13	X	X	X	X
S-14	O	X	X	X
S-15	O	X	O	X
S-16	–	–	–	–
S-17	X	X	X	O
S-18	O	O	O	O
S-19	–	–	–	–
S-20	O	X	O	O
S-21	–	–	–	–
S-22	O	O	O	O
S-23	X	X	O	O
S-24	–	–	–	–
S-25	X	X	O	O
S-26	–	–	–	–
S-27	O	O	O	O

Note: "O" denotes a positive effect on the ports operating cooperatively; "X" denotes a negative effect on the ports operating cooperatively; and "-" indicates no cooperation.

Table 3 summarizes the stakeholders' benefits that can be gained in each scenario in this case. From Table 3, the scenarios in which cooperation benefits both ports and carriers are as follows:

Case-COM (emphasis on improved profits): S-4, S-5 S-7, S-10, S-18, S-22, and S-27;

Case-PUB (emphasis on welfare of local customers): S-11, S-17, S-18, S-20, S-22, S-23, S-25, and S-27.

These scenarios have a positive effect on the carrier. Thus, we can say that there is no reason for the carrier to object to port cooperation. This discussion provides two outcomes.

When each port authority prioritizes its own benefit, port cooperation involving a congested port would be successful. By contrast, when each port authority prioritizes the benefits of its local customers, that is, shipping costs related to both economies of density and port congestion, port cooperation involving a congested port would rarely be successful.

Regarding the first outcome, cooperation involving a congested port may enhance the function distribution for transshipment between ports, raise their charges, and consequently relieve congestion at the congested port. In other words, the port authority under cooperation can slightly change the port charge to enhance the function distribution to reduce congestion. The opposite outcome (i.e., second outcome) is true in cases of an emphasis on the welfare of local customers. When the congested port is in the market, the cooperation between lightly congested ports (S-11) or noncongested ports (S-18) is beneficial to both carriers and ports. Furthermore, other possible combinations, in cases of an emphasis on the welfare of local customers, that are beneficial for the carriers and ports under cooperation include lightly congested and/or noncongested ports. These findings indicate that the strategic cooperation between ports with large capacity for cargo handling can be effective when each port authority considers the benefits of its local customers.

From the above discussion, we obtain the following policy implications.

Under the situation of an emphasis on improved profits, the congested port can have a strong incentive to cooperate. Cooperation can be beneficial to carriers, and therefore, it is supported by the carrier. By contrast, under the situation of an emphasis on the welfare of local customers, cooperation in a scenario that includes a congested port cannot be supported by the carrier. Instead, other types of cooperation (e.g., cooperation excluding a congested port) can be desirable for the carrier. In terms of port capacity, it is rational for the port authority of the congested port to not expand the port capacity and attempt to identify a partner for cooperation in cases of an emphasis on improved profits. However, in cases of an emphasis on the welfare of local customers, the port authority should attempt to expand the port capacity to be classified as a lightly congested or noncongested port and identify a partner classified as a lightly congested or noncongested port for cooperation. Other types of ports rarely have an opportunity to successfully cooperate in cases of an emphasis on improved profit, whereas they have adequate opportunities in cases of an emphasis on the welfare of local customers.

5. Conclusion and further research

This study discussed the possibility of port cooperation in consideration of the operating constraints of each port. We developed a bilevel optimization model that can describe the port competition over the optimal behavior of a monopolistic carrier and performed numerical computations. Thus, we determined some important characteristics of port cooperation that strongly depend on the port conditions. The outcomes suggest that under specific conditions, port cooperation can be successful and beneficial to both carriers and ports. In some areas, including Eastern Asia, several international ports face increased competition because of changes in local supply chains. For survival, the cooperation between and within ports, as discussed in this study, could be a viable option.

Our study has some limitations because we assume an idealistic situation. First, we follow the common assumption that the carrier has its own cargo demand that is inelastic toward the market condition. This indicates the absence of the end-users' choice of service. In long- or mid-term decision making, the end-users (i.e., shippers) can change their carriers, and therefore, the demand is elastic toward the service level. This can be clarified by considering the carrier–user interaction-type bilevel optimization model. However, this modification will make the model structure much more complicated (triple-level optimization) and difficult to solve. The straightforward solution cannot be adopted, and we need to find heuristic approaches. Second, regarding the previous point, we have neglected the competition among carriers. Because the ocean transport market is very oligopolistic, the competition among carriers should be considered accordingly in the analysis, for relaxing the assumption of a monopolist carrier. Third, we adopt a simple model structure with modest assumptions because we aim to discuss the basic function of port cooperation. However, in the real world, each authority has its own motivations and aims. Therefore, it can have its own objective functions and constraints. When we reflect these points to the model structure, the model behavior will become more complicated. As mentioned earlier in this paragraph, to tackle this issue, we should consider other mathematical approaches for finding solutions. Finally, in terms of the shipping route configuration, we deal with a simple hub-and-spoke network and use a single network instance to execute the solution method. However, in the real world, a multiple-ports-of-call voyage is commonly adopted in container transport markets with larger networks. We will address this type of route configuration with more networks in our future research to reflect the real situation by improving our proposed method.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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