EXPLORING THE OPTIMUM COOPERATIVE RELATIONSHIPS OF PORTS IN DIFFERENT MOTIVATIONS

Hoshi TAGAWA[1], Tomoya KAWASAKI[2] and Shinya HANAOKA[3]

[1]Non-Member of JSCE, Doctoral Student, Dept. of Transdisciplinary Science and Eng., Tokyo Tech.
(2-12-1, O-okayama, Meguro-ku, Tokyo,152-8550, Japan)
Email:tagawa.h.ab@m.titech.ac.jp
[2]Member of JSCE, ember of JSCE, Lecturer, Dept. of Systems Innovation, The University of Tokyo.
[3]Member of JSCE, , Professor, Dept. of Transdisciplinary Science and Eng., Tokyo Tech.

The motivation of port cooperation is divided into two; regional welfare or competition. This study examines the effectiveness of port cooperation for competition and the difference of optimum cooperation strategy for each motivation by a game theoretical model. We derive and compare the cooperative effort, which indicates the willingness to attend the port cooperation as an optimum cooperation to fit each motivation. We find that optimum cooperation levels in cooperation for regional welfare and for competition are different due to the difference of cooperation effects in each motivation. Cooperation for competition often requires higher cost reduction to realize high competitiveness with higher cooperation level. On the other hands, there are several situations where cooperation for regional welfare requires higher cooperation level than cooperation competition.

Key Words : *multiple ports; cooperation; competition; game theorical model*

1. INTRODUCTION

Container ports serve as functions for facilitating the efficient flow of container cargo. The increase of cargo throughput results in an increase of economic welfare beyond the container port stakeholders to the entire port region (Goss 1990 and Notteboom and Yap 2012). Port management bodies have developed various port strategies to increase the cargo throughput. Port cooperation, which is defined as a relation between two or more parties with compatible or additional interests or aims (Donselaar and Kolkman 2010), is considered as one of the effective strategies to improve their productivity or profitability of ports (Takebayashi and Hanaoka 2021). Port industry has experienced a multiplication of port cooperation in recent years (Notteboom et al. 2018). In the cooperation between Ningbo and Zhoushan ports in China, for example, port planning and investments and the management of the port coastline are integrally implemented (Notteboom and Yang 2017). Rotterdam and Amsterdam ports in Netherlands invest a company that offers paths of trains between Dutch seaports and the European hinterland (Donselaar and Kolkman 2010). There are various types of port cooperation that have different business scope such as terminal management and hinterland access (Inoue 2018). Optimum port cooperation depends on the situations surrounding ports such as port congestion (Takebayashi and Hanaoka 2021) and similarity of ports (Cui and Notteboom 2018).

For these various cooperation types, the motivation of the ports is divided into two; regional welfare or competition. A regional welfare problem is to increase the welfare of common region with cooperative ports with solving common problem such as hinterland congestion and duplication in port facility . As an example, in Dalian and Yingkou ports in China joint port operation and management are planned 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 the reginal welfare. A competition problem is facing a loss of market share from neighboring ports because of a strong competitor. As an example, the Seattle and Tacoma ports in the northwestern 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 Vancouver port (Inoue 2018). Port cooperation aims to realize higher market share than the competitor by higher competitiveness from the synergy such as economies of scale. The major difference between cooperation for regional welfare and competition is the focusing market in the cooperation. Specifically, cooperation for regional welfare focus on the market with ports that try to cooperate. Cooperation for competition focus on the market with ports that try to cooperate and another competitor.

While many studies have examined port cooperation, most have focused on cooperation for reginal welfare. Munim and Haralambides (2018), for example, analyzed that the cooperation among Kolkata ports in India and Mongla and Chittagong ports in Bangladesh benefited the overlapping port user. Wang et al. (2012) explained that port cooperation in maximizing joint profit resulted in the higher port charge and their profits increase simultaneously compared with those in competition. These studies showed that port cooperation achieved win-win relationships with the increase of regional welfare; former study in reduced transportation costs of shipper and latter study in increase of each profit. On the other hand, cooperation for competition, which is one of the major motivations for cooperation, has not been fully analyzed. There is a research gap whether cooperation is effective for competition or not. Additionally, if we apply the findings of previous studies in cooperation for regional welfare, reduced transportation costs of shipper can contribute to cooperation for competition. However, higher prices for increase of each profit does not fit the motivation of cooperation for competition, because port should set lower price in competitive situation (Ishii et al. 2013). This application reveals the research question whether the optimum cooperation to fit motivation is different or not.

This study aims to reveal the effectiveness of port cooperation for competition and the difference of optimum cooperation for each motivation which include cooperation for regional welfare and for competition. We propose a game theoretical model with market participants including shipper and port. Specifically, we analyze the three ports competing or cooperating in linear city that shippers are uniformly distributed based on Zhou (2015), Wan et al. (2016) and Kawasaki et al. (2021). Port determine each port charge and shipper choose the port to use in the model. We derive and compare the cooperative effort, which indicates the willingness to attend the port cooperation (Kavirathna et al. 2019 and Dong et al. 2018), as an optimum cooperation to fit each motivation with considering behavior of port and shipper. We analyze four scenarios where we change land cost, port competitiveness, public level and cost reduction by cooperation to simulate several port situations.

The rest of this paper is structured as follows. Section 2 show reviews of the existing literature on port cooperation. Section 3 explains a game theoretical model. The results are appeared in Section 4. Finally, Section 5 conclude this study and show directions for further research.

2. LITERATURE REVIEW

Port cooperation have been researched by many studies in recent years. Several studies showed port cooperation improve productivity of ports. Guo et al (2018) analyzed integration problem in a multi-port region that is the most aggressive way to cooperate. They proposed the method to determine the optimal scale of cooperative ports, which include the number of ports, corresponding port sizes and location sites, to maximize social welfare. Trujilo et al. (2018) showed that collusive agreement about the optimal total capacity in cooperative ports realized higher profits for both ports by exploiting economies of scale. Yang et al. (2019) analyzed the optimal scale of cooperative ports to minimize costs with port industry transformation and upgrading. Donselaar and Kolkman (2010) mentioned that cooperation can solve the problem of less necessary port-related investment by competition. Munim and Haralambides (2018) indicated that shipper in two landlocked countries in South Asia, Nepal and Bhutan, benefited from cooperation among Kolkata port in India and Mongla and Chittagong ports in Bangladesh.

Several studies have showed the conditions required to realize the port cooperation with win-win relationships instead of port competition. Takebayashi and Hanaoka (2021) revealed that the port cooperation in a congested port was successful when each port authority considers the benefit of its local customers in terms of shipping costs. Cui and Notteboom (2018) analyzed the factor to promote port cooperation in similarity of ports and privatization. Wang et al. (2012) concluded that port cooperation was established only when there was a balance between the price rising effect, which is to increase port price, and output switching effect, which is to switch some of the throughput from high cost ports to low cost ones. Kawasaki et al. (2020) demonstrated that ports should keep competition rather than cooperation in low cargo demand. Knatz (2018) mentioned that Los Angeles and Long Beach ports, which are in proximity, have failed to build cooperative relationship due to the lack of clear benefits to each port and city.

Several studies have analyzed the importance of the right balance between competition and cooperation as coopetition proposed by Song (2003). Dong et al. (2018) concluded that once the degree of port cooperation exceeds the threshold, the container throughput experiences a slowdown in growth or even negative due to the diseconomies of scale. Lee and Song (2017) mentioned that although the concept of port coopetition had existed for a decade, empirical or modelling research has not fully implemented. There are several studies not about port coopetition but about coopetition of other players in maritime transport such as shipping line and terminal operator. Lin et al. (2017), for example, derived the optimum coopetition level of shipping lines to maximizer own profit. The optimum levels were changed depending on path cost and market size. Kavirathna et al. (2019) analyzed coopetition of terminal operator and showed operator incentives change depending on the combinations of terminal ownership.

In summary, previous studies demonstrated that port cooperation contributed to the improvement of port productivity. Additionally, optimum port cooperation depends on the situations surrounding ports and the right balance between competition and cooperation as coopetition was important. However, while required conditions and achievement in cooperation for regional welfare have been fully analyzed, cooperation for competition have not. The significance of this study lies in suggesting whether cooperation is effective for competition or not and reveling the difference of optimum cooperation for each motivation which include cooperation for regional welfare and for competition in several port situations. We can apply the knowledge about cooperation for regional welfare to cooperation for competition based on the difference obtained from this study. The achievement contributes to policymakers engaged in ports by serving methodological reference for port cooperation.

3. METHODOLOGY

(1) Model setting

We simulate three ports located at the linear city where shippers as the cargo owner are uniformly distributed with a density of one shipper based on Zhou (2015), Wan et al. (2016) and Kawasaki et al. (2021) as shown in Figure 1. Each port located at the position d_i in one-dimensional space represented as r-axis. We set, without loss of generality, port 2 at the central point($d_2 = 0$). The linear city represent market where each port focus and highlight the impact of port strategy change such as cooperation or competition on shippers with simplified calculation. Shippers

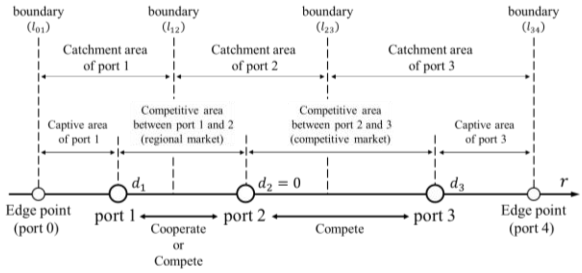


Fig.1 Basic setting of a linear city.

located in the area between two ports, which we name competitive area, decide to use either port based on the comparison of utility of ports. There is a shipper who is indifferent between using either port due to the same utilities of both ports, which we regard as boundary of ports. Shippers located in the area except for competitive area, which we name captive area, decide to use port based on the utility of port. Those decision of shipper result in the occurrence of boundary where most distant shipper locate, which is regarded as edge point. We virtually set port 0 and 4 to represent the boundaries as edge point with understandable formulation. The locations of boundaries can change with changes in utility caused by changes in cooperative strategy. Catchment area of ports are area between the boundaries.

Ports are cooperating or competing in the linear city. Specifically, port 1 and 2 determine the own strategies such as cooperation or competition in the situation where port 2 and 3 compete. The focused market to determine the strategy changes depending on the motivation of cooperation. Specifically, cooperation for regional welfare focuses on the market where shipper located between port 1 and 2, which we name regional market. Ports determine cooperative strategy to increase the welfare of region shared with cooperative ports. Cooperation for competition focuses on the market where shipper located between port 2 and 3, which we name competitive market. Ports determine cooperative strategy to gain a market share in the region shared with another competitor. We calculate the optimum cooperative strategy on regional welfare and competition separately and measure the difference of obtained optimum strategy.

We consider two issues for cooperation in addition to motivation as shown in Table 1; effect and type. First, we consider two effects in the port cooperation; cost reduction and higher market power. Port cooperation can realize cost reduction by efficiency improvement such as prevention of overcapacity and economy of scale (Donselaar and Kolkman 2010). As

for market power, cooperation leads to higher market power instead of less competition between cooperative ports, which result in higher port charge (Donselaar and Kolkman 2010 and Saeed and Larsen 2010). In the simulation, we formulate to reflect these

Table 1. Cooperation issues in the simulation

Motivation	Regional welfare	To increase the welfare of region shared with cooperative ports
	Competition	To gain a market share in the region shared with strong competitor
Effect	Cost reduction	Efficiency improvement realizes the cost reduction
	Market power	Higher market power results in higher port charge
Type	Hinterland access	Improvement of accessibility to both ports
	Terminal management	Improvement by the integrated terminal management

two effects. Finally, two cooperation types, which indicates the business scope covered in the cooperation, are considered; hinterland access and terminal management. We assume that the cooperation realizes the reduction in cost covered by each type. Specifically, the cost reduction in hinterland access is realized by the cooperation to improve the accessibility to both involving cooperative ports. As an example, Los Angeles and Long Beach in the US developed an efficient rail corridor of enough capacity for the two rapidly growing ports (Inoue 2018). The cost reduction in terminal management is realized by the integrated management of the two ports. As an example, Kobe and Osaka in Japan established joint management company to develop the efficient and non-duplication terminal (Inoue 2018). We separately simulate the two types cooperation to analyze whether different cooperation types occur different result.

(2) Model development

We apply three stages model in the linear city as shown in Figure 2. In the first stage, cooperation level (z) that takes the value from 0 to 1 $(0 \leq z \leq 1)$. If the cooperation value is 0, the two ports are perfectly competitive. Perfect competitive ports value only own benefit in the decision. If the cooperation value is 1, the two ports are perfectly cooperative. Perfect cooperative ports value the benefit of partner port as much as own benefit in the decision. If the cooperation value is larger than 0 and less than 1, two ports simultaneously characterizes both competition and cooperation, which is known as coopetition (Song 2003 and Kavirthna et al. 2019). Although coopetition ports value both benefits, each port value own benefit more than partner port. The objective functions to determine cooperative level change depending on the motivations. In cooperation for regional welfare, generalized cost of shipper in regional market is minimized to increase the welfare of region shared with cooperative ports. In cooperation for competition, generalized cost of shipper in regional market is minimized to gain a market share in the region shared with another competitor. We measure the difference of optimum cooperation level between two motivations. In the second stage, port charge (w_i) of each port is to determine to maximize benefits of port. In the third stage, shipper determine the port to

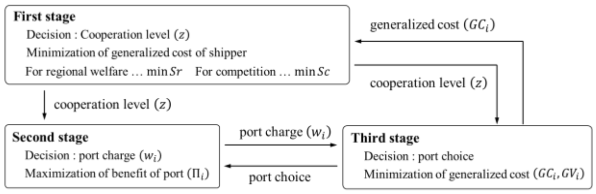


Fig.2 Model overview.

use based on the generalized cost as utility of port to transport the own cargo. The game is solved by backward induction. We start the explanation with the third stage to fit the backward induction. The notations of the model are as follows;

i, j	Port name (0 and 4 are virtual ports to identify the edge points in the formulation)
GC_i	Generalized cost of shipper to use port i in competitive area
GV_i	Generalized cost of shipper to use port i in captive area
π_i	Regional benefit of port i
Π_i	Benefit of port i
Sr	Average generalized cost of shipper in shared market with cooperative port
Sc	Average generalized cost of shipper in shared market with competitive port
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	Land transport cost per distance in competitive area
cv	Land transport cost per distance in captive area
cp_i	Cost of port i
ch_i	Fixed land transport cost 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

a) Third stage: cargo through put

In the third stage, we calculate the cargo throughput (x_i) in each port based on the shippers' choice. As mentioned, shipper determine the port to use based on the utility of ports. We calculate the utility of ports as generalized cost. Shipper in competitive area chooses the port with lower generalized cost (GC_i). In captive area, shipper with lower generalized cost (GV_i) than reservation price (V) choose the port to use.

Figure 3 indicates the generalized cost of shipper in the linear city. Equations (1) shows the generalized

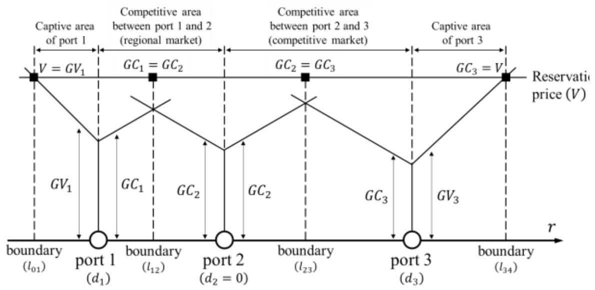


Fig.3 Generalize cost of shipper in the linear city

cost in competitive area and captive area, respectively, for port 1 to 3. The generalized cost consists of port charge (w_i), land transport cost (cs, cv) and hinterland cost (ch_i). Port charge represents the service price per unit charged by port, which is determined to maximize the regional benefit in second stage. Land transport cost represents the cost increasing with the distance such as fuel or labor cost. We set different transport cost in competitive area (cs) and captive area (cv). We assume that competitive and captive area are near city and rural area, respectively. The transport cost in competitive area is smaller than captive area, because we assume that city area has well-developed infrastructure and required time is navigation time is smaller than rural area in same distance. Distance from the port, which is calculated by the location of shipper (r) and port (d_i), is multiplied to the transport cost per distance. Hinterland cost (ch_i) represents the unchanged cost per distance in each port with distance such as congestion cost. Generalized cost increases as the distance from port increase as shown in Figure 3. There are shippers who have same generalized cost in competitive area.

The land transport and hinterland costs are reduced by the cooperation in hinterland access improvement as the cooperation effect. We calculate the amount of cost reduction in accordance with cooperation level (z) and reduction ratio (α). The formulation as $(1 - \alpha \cdot z)$ represents that the amount of reduction increases as the cooperation level increase. The reduction ratio depends on the cooperation type and range from 0 to 1 ($0 \leq \alpha \leq 1$).

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

Shipper determine the port to minimize own generalized cost. In competitive area, boundary points between two adjacent ports (l_{12}, l_{23}) are the points where the generalized cost of both ports are the same. In captive area, boundary points (l_{01}, l_{34}) are the points where the generalized cost and reservation price are same (Wan et al. 2016 and Kawasaki et al. 2021). Equations (2) indicates the boundary conditions.

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

We can calculate the cargo throughput in each port based on the size of catchment area, because the density of one shipper in the linear city. Equations 3 indicates the cargo throughput in each port. The negative value of differentiation ($\partial x_1/\partial w_1 < 0,\ \partial x_2/\partial w_2 < 0, \partial x_3/\partial w_3 < 0$) indicates that the size of catchment area and cargo throughput decrease as each port charge increase.

$$
\begin{aligned}
&x_1 = \int_{l_{01}}^{l_{12}} 1\ dr = l_{12} - l_{01}\\
&x_2 = \int_{l_{12}}^{l_{23}} 1\ dr = l_{23} - l_{12}\\
&x_3 = \int_{l_{23}}^{l_{34}} 1\ dr = l_{34} - l_{23}
\end{aligned} \tag{3}
$$

b) Second stage: port charge

In the second stage, we calculate the port charge based on the benefit of each ports (Π_i). Ports determine each port charge to maximize own benefits. Benefits of port consists of regional benefits of own port (π_i) and partner port in case of cooperation as shown in Equations (4). The combined benefit in cooperative ports lead to collusive agreement to make higher port charge, which indicates the market power as the cooperation effect. We formulate that as cooperation level increases, port becomes to place more importance of combined benefit.

$$
\begin{aligned}
&\max_{w_1} \Pi_1 = \pi_1 + z \cdot \pi_2\\
&\max_{w_2} \Pi_2 = \pi_2 + z \cdot \pi_1\\
&\max_{w_3} \Pi_3 = \pi_3
\end{aligned} \tag{4}
$$

Equations (5) show benefit of each port. The benefit of port consists of the profit of port from the port charge and benefit of port users. The profits of port consist of port charge as revenue (w_i) and cost of port (cp_i). The cost of port represents the cost increasing with the cargo such as loading and unloading cost and are reduced by the cooperation in terminal management as the cooperation effect. The cost reduction by cooperation can be calculated with cooperation level and reduction ratio (β). The formulation as ($1-\beta \cdot z$) represents that the amount of reduction increases as the cooperation level increase. Reduction ratio depend on the cooperation type and range from 0 to 1 ($0 \leq \beta \leq 1$).

As for user's benefits, we calculate the average generalized transportation cost of shipper per unit in each catchment area of port. The calculations of average cost are shown by integral function in Equation (5). We balance the weight of profit of port and average cost of shipper in benefit of port by parameter as public level (u_i). When the value is low, port becomes more sensitive to own profit, which indicates the characteristic of private port. Other studies such as Cui and Notteboom (2018) and Takebayashi and Hanaoka (2021) use this parameter to represent the characteristic of private and public ports.

$$\begin{aligned}
\pi_1 &= (w_1 - (1-\beta \cdot z)cp_1)x_1 \\
&\quad - u_1\left(\frac{\int_{l_{01}}^{d_1} GV_1\,dr}{d_1 - l_{01}} + \frac{\int_{d_1}^{l_{12}} GC_1\,dr}{l_{12} - d_1}\right) \\
\pi_2 &= (w_2 - (1-\beta \cdot z)cp_2)x_2 \\
&\quad - u_2\left(\frac{\int_{l_{12}}^{0} GC_2\,dr}{-l_{12}} + \frac{\int_{0}^{l_{23}} GC_2\,dr}{l_{23}}\right) \\
\pi_3 &= (w_3 - cp_3)x_3 \\
&\quad - u_3\left(\frac{\int_{l_{23}}^{d_3} GC_3\,dr}{d_3 - l_{23}} + \frac{\int_{d_3}^{l_{34}} GV_3\,dr}{l_{34} - d_3}\right)
\end{aligned} \tag{5}$$

We obtain the optimum port charge (w_i) to maximize benefits based on the first order conditions. We solve the simultaneous equation from the first order conditions as shown in Equations (6).

$$\begin{pmatrix} \frac{\partial \Pi_1}{\partial w_1} \\ \frac{\partial \Pi_2}{\partial w_2} \\ \frac{\partial \Pi_3}{\partial w_3} \end{pmatrix} = 0 \leftrightarrow A\begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} + b = 0 \leftrightarrow \begin{pmatrix} w_1 \\ w_2 \\ w_3 \end{pmatrix} = -A^{-1}b \tag{6}$$

c) First stage: cooperation level

In the first stage, we calculate the cooperation level (z) based on minimization of generalized cost of shipper. The generalized cost of shipper focused in port cooperation changes depending on the motivations. Specifically, cooperation for regional welfare focuses on the shipper shared with cooperative port that is area shared with port 1. Cooperation for competition focuses on the shipper shared with competitive port that is area shared with port 3. Figure 4 indicates each focusing market in the linear city. We calculate the optimum cooperation level to minimize the average generalized cost in each motivation.as shown in Equations (7). Terms Sr and Sc represent the average generalized cost in the cooperation for regional welfare, competition and both, respectively.

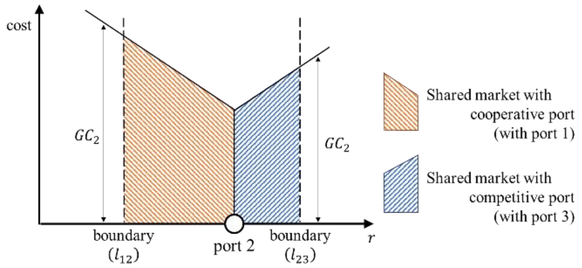


Fig.4 Focused shipper in each coopearation motivation

(3) Input values and scenraios

In this study, we derive the optimum cooperation level to fit motivation. However, we cannot obtain clear and tractable conditions that cause the difference in the optimum cooperation values due to the complexity of the calculations. Therefore, we conduct numerical analysis to explore the difference in the optimum cooperation. Table 2 indicates the input values as base case. We prepared two pairs of reduction ratios to represent two cooperation types which include hinterland access and terminal management. Specifically, we set the value of hinterland cost reduction ratio to 0.20 and port cost reduction ratio to 0 to realize twenty percent reduction of hinterland access cost in hinterland cooperation.

$$\begin{aligned}
\min_z Sr &= \frac{\int_{l_{12}}^{0} GC_2\,dx}{0 - l_{12}} \\
&= w_2 \\
&\quad - (1-\alpha \cdot z)\left(\frac{1}{2}cs \cdot l_{12} - ch_2\right) \\
&= \frac{1}{4}w_1 + \frac{3}{4}w_2 \\
&\quad - \frac{1}{4}(1-\alpha \cdot z)(cs \cdot d_1 - ch_1 \\
&\quad - 3ch_2) \\
\min_z Sc &= \frac{\int_{0}^{l_{23}} GC_2\,dx}{l_{23} - 0} \\
&= w_2 \\
&\quad + (1-\alpha \cdot z)\left(\frac{1}{2}cs \cdot l_{23} + ch_2\right) \\
&= \frac{3-\alpha \cdot z}{4-2\alpha \cdot z}w_2 + \frac{1-\alpha \cdot z}{4-2\alpha \cdot z}w_3 \\
&\quad + \frac{1-\alpha \cdot z}{4-2\alpha \cdot z}(cs \cdot d_3 \\
&\quad - (3-\alpha \cdot z)ch_2 + ch_3)
\end{aligned} \tag{7}$$

Table 2. Input values for numerical analysis in base case

			Cooperation type	
			Hinterland	Terminal
Hinterland cost reduction ratio		α	0.20	0
Port cost reduction ratio		β	0	0.20
Reservation price		V	10	
Location of port	Port 1	d_1	-2.0	
	Port 2	d_2	0	
	Port 3	d_3	3.0	
Hinterland cost	Port 1	ch_1	2.5	
	Port 2	ch_2	2.0	
	Port 3	ch_3	1.5	
Cost of port	Port 1	cp_1	2.5	
	Port 2	cp_2	2.0	
	Port 3	cp_3	1.5	
Public level	Port 1	u_1	1.0	
	Port 2	u_2	1.0	
	Port 3	u_3	1.0	
Land transport cost in competitive area		cs	2.0	
Land transport cost in captive area		cv	3.0	

We consider four scenarios to simulate several port situations; land, port, public and reduction. In land scenario, we change the value of land transport cost in competitive area (cs) in the range from 1.0 to 5.0 and it is maintained the value of transport cost in captive area is larger than competitive area ($cv = cs + 1$) with the same other values in base scenario, respectively. This scenario represents the impact of hinterland access cost on the optimum cooperation level. Wan et al. (2018) emphasized the importance of hinterland cost in port competition. In port scenario, we change the value of fixed hinterland cost and cost of port 2 (ch_2, cp_2) in the range from 1.0 to 5.0 with the same other values in base scenario. This scenario represents the impact of cooperation with different port competitiveness on the optimum cooperation level, because shipper decide to use the port with lower cost and hinterland connection as higher competitiveness port (Yuen et al. 2012). Cui and Notteboom (2018) and Wang et al. (2012) concluded that similarity of port competitiveness such as the level of service quality and accessibility is influential factor to realize port cooperation. In public scenario, we change the value of public level of port 2 (u_2) in the range from 0.0 to 2.0 with the same other values in base scenario. This scenario represents the impact of cooperation with different port governance on the optimum cooperation level. Cui and Notteboom (2018) and Takebayashi and Hanaoka (2021) revealed the importance to consider the port governance (public or private) to realize port cooperation. In reduction scenario, we change the value of cost reduction ratio (α, β) in the range from 0.1 to 0.5 with the same other values in base scenario. This scenario represents the impact of cooperation with different cost reduction as cooperation effect. Knatz (2018) pointed out the importance of benefits for both ports in the cooperation.

4. RESULTS AND DISCUSSION

(1) Base case

Figure 5 shows the average generalized cost focused in each motivation with cooperation level. The average costs are concavity function with cooperation level and reach the minimum in the extreme values. This result indicates that port cooperation is effective port strategy for competition by reducing the cost in competitive area. The cost in competitive area becomes minimum when port realize a well-balance between cooperation and competition as optimum cooperation level.

The optimum cooperation levels are different on the motivations in both cooperation types. Specifically, the values in cooperation for regional welfare are 58.5% and 29.2% in hinterland access and terminal management, respectively. The values in cooperation for competition are 65.6% and 31.5% in hinterland access and terminal management, respectively. The optimum cooperation level of cooperation for competition is higher than for regional welfare. Those difference of cooperation levels is due to the difference of cooperation effects in each motivation. We set the optimum cooperation level to balance the cost reduction and higher market price, which are the cooperation effects, for minimizing average cost in each motivation. Cooperation for competition require higher cost reduction to realize high competitiveness. Cooperation for regional welfare needs to prevent the increase of port charge by higher market power. This result indicates the importance to build the different strategy in the different cooperation motivations.

Table 3 shows values of average generalized cost, port charges and boundary points when the generalized cost becomes minimum in each cooperation type and motivation. The port charge of port 1 and 2 in cooperation for competition is higher than for reginal welfare in hinterland cooperation. This result is not in line with intuition that competition result in lower port charge. We can solve the problem by the cost reduction as one of the cooperation effects. Cooperation in hinterland access realize the reduction of hinterland access cost and the amount of reduction change with cooperation level. Although port charge increases by the increase of market power with cooperation level as cooperation effect, the amount of reduction is larger than the increase. The larger reduction realizes lower average cost in shared market with

Table 3. Results of generalized costs, port charges and boundary points in base case

Cooperation type		Hinterland access		Terminal management	
Cooperation Motivation		Regional welfare	Competition	Regional welfare	Competition
Average generalized cost	Cooperative port (Si)	7.0674	7.0695	7.1579	7.1580
	Competitive port (Sc)	7.4138	7.4120	7.5149	7.5148
Port charge	Port 1 (w_1)	4.2951	4.3498	3.9429	3.9435
	Port 2 (w_2)	4.3115	4.3560	4.0630	4.0629
	Port 3 (w_3)	4.2746	4.2653	4.3706	4.3706
Boundary	Port 1 and 0 (l_{01})	-3.3219	-3.3345	-3.1857	-3.1855
	Port 1 and 2 (l_{12})	-1.1203	-1.1232	-1.0950	-1.0952
	Port 2 and 3 (l_{23})	1.5125	1.5175	1.4519	1.4519
	Port 3 and 4 (l_{34})	4.4085	4.4116	4.3765	4.3765

competitive port (Sc). Additionally, the lower average cost result in moving boundary between port 2 and 3 (l_{23}) to the right that is expansion of catchment area of port 2 in competitive area with port 3.

As for the cooperation in terminal management, port charge of port 1 in cooperation for regional welfare is lower than competition and port charge of port 2 in cooperation for regional welfare is higher than competition. This reflects the difference of requirements in motivations. Cooperation for regional welfare requires the minimization of generalized cost shred with cooperative ports that are port 1 and 2. Thus, port charge of port 1and 2 becomes lower optimum cooperation level for regional welfare. On the other hand, cooperation for competition requires the minimization of generalized cost shared with competitive ports that are port 2 and 3. Port charge of port 1 can be higher if port charge of port 2 do not increase, because port charge of port 1 does not affect on the competition. Those different requirements result in different optimum cooperation level in Figure 5. Note that the difference of values in different motivation and same type are not so large. Specifically, the difference occurs in the fourth decimal place. If the wrong optimum cooperative relationships are constructed, such as cooperation for regional welfare realize optimum cooperation level in competition without considering the difference, the results do not drastically change.

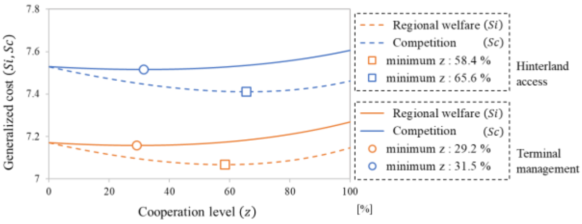


Fig.5 Generalize cost focused on each type and motivation

(2) Scenario analysis

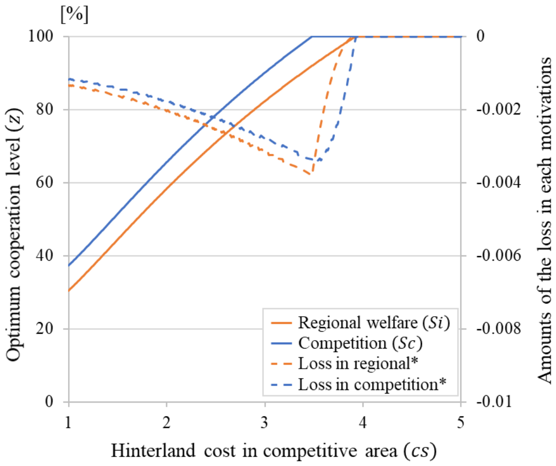
a) Land scenario

Figure 6 shows the optimum cooperation level that minimize generalized cost in each type and each motivation with land scenario. This scenario is to simulate the impact of hinterland access cost on the optimum cooperation level. Although the gradients are different, both cooperation types require hither cooperation level as hinterland cost becomes higher and they finally require complete cooperation ($z = 100$). This indicates that the different cooperative relationships should be constructed on development of hinterland. Specifically, ports in low hinterland cost area with highly developed hinterland access should construct competitive relationships. On the other hand, ports in high hinterland cost area with less developed hinterland access should construct cooperative relationships.

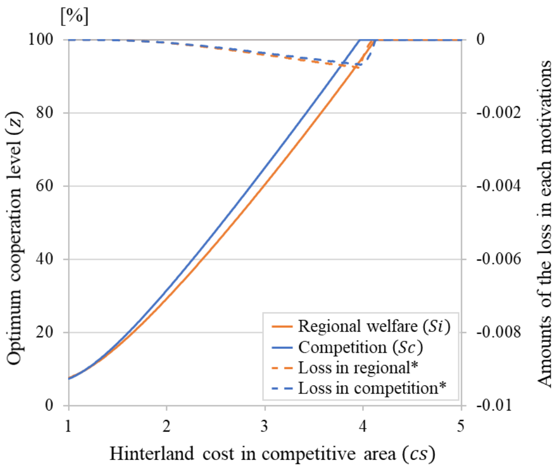
As for the difference of motivations, cooperation for competition requires higher cooperation level in both cooperation type same as base case. The required cooperation effects are different between motivations in each land cost. Figure 6 also shows the loss of average generalized cost focused in each motivation when wrong optimum cooperation is constructed; cooperation for regional welfare, for example, realize optimum cooperation level in competition without considering the difference of motivations. The loss increases until competition requires complete cooperation. Although, the loss of hinterland access occurs in the third decimal place and is not so large same as base case, the loss changes depending on the hinterland cost.

b) Port scenario

Figure 7 shows the optimum cooperation level in each type and each motivation and the loss in wrong cooperative motivations with port scenario. This scenario is to simulate the impact of cooperation with different port competitiveness on the optimum cooperation level. Although the gradients are different, both cooperation types require hither cooperation level as port cost becomes higher and they finally require complete cooperation same as land scenario. This indicates that the different cooperative relationships should be constructed on port competitiveness. High competitiveness ports with low port cost should



(a)



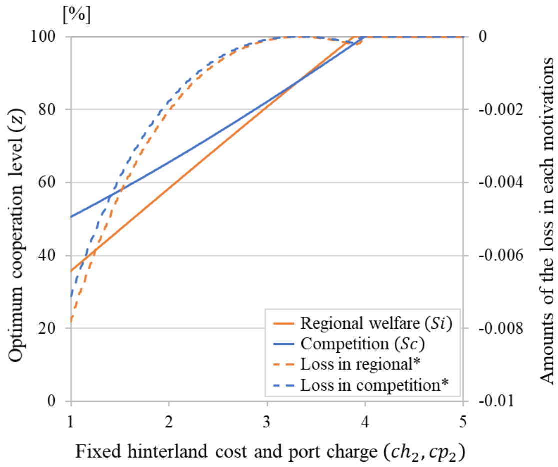
(b)

Fig.6 Land scenario (a) Hinterland access (b) Terminal management

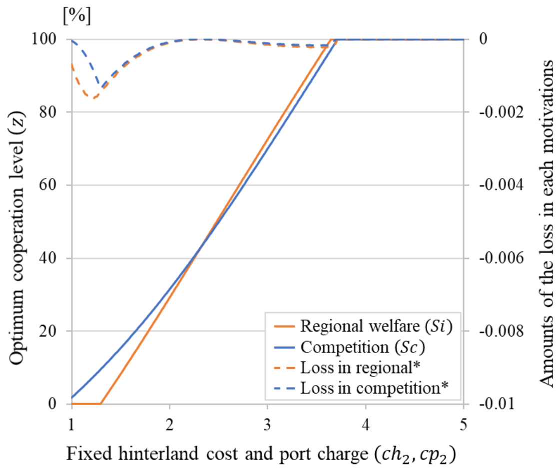
* Loss average generalized cost focused in each motivation when wrong optimum cooperative relationships are constructed

construct competition. On the other hand, low competitiveness ports with high port cost should construct cooperation.

As for the difference of motivations, different gradients of optimum cooperation level result in the different magnitude relationships. Specifically, cooperation for competition requires higher cooperation level than cooperation for regional welfare in low port cost. On the other hand, it requires lower cooperation level in high port cost. Low competitiveness ports with high port cost require higher cost reduction in cooperation for regional welfare than competition unlike base case and land scenario. The loss is larger in low port cost area where there is a higher gap of optimum cooperation level between motivations. The loss still occurs after the turning point where magnitude relationships change. The amount of loss after the turning point is smaller than before the turning point. The required cooperation effects change depending on the port competitiveness.



(a)



(b)

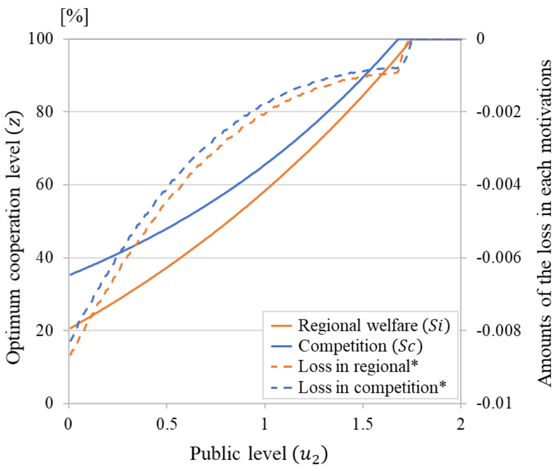
Fig.7 Port scenario (a) Hinterland access (b) Terminal management

* Loss average generalized cost focused in wrong motivation

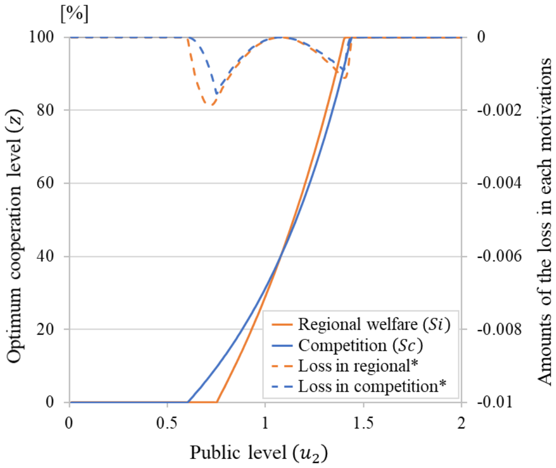
c) Public scenario

Figure 8 shows the optimum cooperation level in each type and each motivation and the loss in wrong cooperative motivations with public scenario. This scenario is to simulate the impact of cooperation with different port governance on the optimum cooperation level. Although the gradients are different, both cooperation types require hither cooperation level as port considers the local shipper's cost to be more important as public port. Additionally, both cooperation types require hither cooperation level as hinterland cost becomes higher and they finally require complete cooperation ($z = 100$). This result indicates that private ports require port competition and public port require cooperation.

As for the difference of motivations, the magnitude relationships between regional welfare and competition are different on cooperation types. In cooperation in hinterland access, cooperation for competition requires higher cooperation level than regional welfare same as base case and land scenario. The loss is larger in low public level area where there is a higher



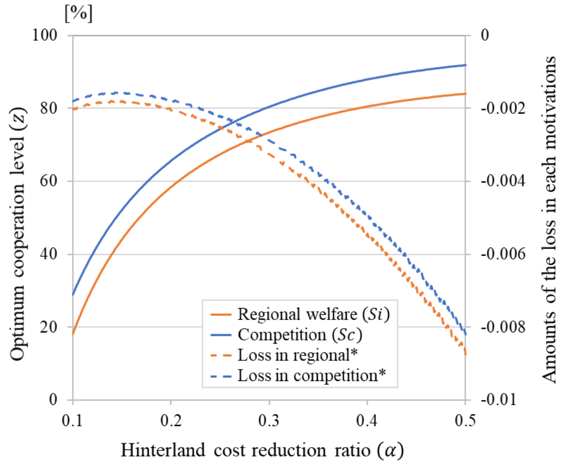
(a)



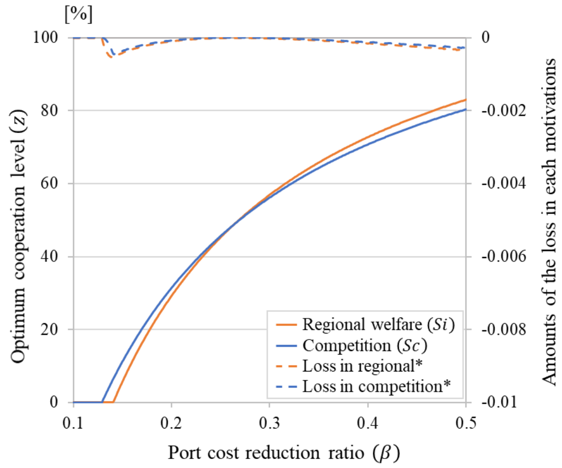
(b)

Fig.8 Public scenario (a) Hinterland access (b) Terminal management

* Loss average generalized cost focused in wrong motivation



(a)



(b)

Fig.9 Reduction scenario (a) Hinterland access (b) Terminal management

* Loss average generalized cost focused in wrong motivation

gap of optimum cooperation level between motivations. Private port cause larger loss by realizing wrong optimum cooperation. The difference of optimum cooperation level between motivations in same public level becomes smaller as public level increase. In cooperation in terminal management, different gradients of optimum cooperation level result in the different magnitude relationships. Cooperation for competition requires higher cooperation level in private port and lower in public port. The required cooperation effects change depending on the public level and motivation.

d) Reduction scenario

Figure 9 shows the optimum cooperation level in each type and each motivation and the loss in wrong cooperative motivations with port scenario. This scenario is to simulate the impact of cooperation with different cost reduction as cooperation effect. Although the gradients are different, both cooperation types require hither cooperation level as hinterland cost becomes higher. They do not require complete cooperation unlike land, port and public scenarios. The different cooperation should be constructed based on the cost reduction by cooperation. Ports where high cost reduction is expected should construct competition. Ports where low cost reduction is expected should construct cooperation.

As for the difference of motivations, the magnitude relationships between regional welfare and competition are different on cooperation types same as public scenario. In cooperation in hinterland access, cooperation for competition requires higher cooperation level than regional welfare. In cooperation in terminal management, cooperation for competition is higher in low cost reduction and lower in high cost reduction. The required cooperation effects change depending on the amount of reduction and motivation same as public scenario.

(2) Summary and discussion

Table 4 indicates the optimum cooperation level in scenario, cooperation type and motivation. We picked out low and high value in each scenario. Based on the results reported in the previous section and Table 4, we can summarize following two find-

Table 4. Optimum cooperation level in scenario, cooperation type and motivation

Cooperation type		Hinterland access		Terminal management	
Cooperation Motivation		Regional welfare	Competition	Regional welfare	Competition
Base case		58.4	65.6	29.2	31.5
Land scenario	Low land cost $cs = 1.5, cv = 2.5$	44.5	51.4	16.2	17.0
	High land cost $cs = 3.0, cv = 4.0$	82.3	90.1	60.4	65.0
Port scenario	Low port cost $cp_2 = 1.5, ch_2 = 1.5$	47.1	57.8	8.2	15.3
	High port cost $cp_2 = 3.5, ch_2 = 3.5$	91.7	91.0	94.0	91.1
Public scenario	Low public level $u_2 = 0.8$	49.4	57.9	5.2	13.4
	High public level $u_2 = 1.2$	68.2	74.3	59.8	56.4
Reduction scenario	Low reduction ratio $ua = 0.15$ or $ub = 0.15$	44.0	52.0	5.6	11.3
	High reduction ratio $ua = 0.30$ or $ub = 0.30$	73.4	80.4	57.0	56.3

*Under lined values are higher optimization level on the motivation

ings about the difference between cooperation for regional welfare and competition.

First, the optimum cooperation levels in cooperation for regional welfare and for competition are different in many cases. The cases where the optimum cooperation levels are same as follows; turning point where the magnitude relationship regional welfare and competition, perfect cooperation and perfect competition. The number of situations where cooperation for competition requires higher cooperation level than cooperation for regional welfare is larger. Those difference of cooperation levels is due to the difference of cooperation effects in each motivation. Cooperation for competition requires higher cost reduction to realize high competitiveness in many situations. Cooperation for regional welfare needs to prevent the increase of port charge by higher market power. However, different gradients of optimum cooperation level result in the different magnitude relationships. There are several situations where cooperation for regional welfare requires higher cooperation level than cooperation competition; both cooperation types in high port cost, terminal management in high public level and high reduction ratio. This result indicates the importance of considering the difference of motivation to realize effective port cooperation.

Second, the loss of average generalized in wrong cooperation change depending on the port situations. The loss is larger in areas where there is a higher gap of optimum cooperation level between motivations. Specifically, the loss is large in hinterland access in middle hinterland cost, low port charge, low public level and high reduction ratio. The gap of loss in each situation is due to the difference of cooperation effects in each motivation same as first finding. Although the loss by wrong cooperation is not so large in the total cost, policymakers should consider the loss to realize best cooperation for each port.

5. CONCLUSION

This study examines the effectiveness of port cooperation for competition and the difference of optimum cooperation for each motivation which include cooperation for regional welfare and for competition by a game theoretical model. We analyze the three ports competing or cooperating in linear city that shippers are uniformly distributed. We derive and compare the cooperative effort, which indicates the willingness to attend the port cooperation as an optimum cooperation to fit each motivation with considering behavior of port and shipper. This study reveals following three findings about port cooperation. First, port cooperation is effective port strategy for competition by reducing the cost of shipper in competitive area. The cost in competitive area becomes minimum when port realize a well-balance between cooperation and competition as optimum cooperation level. Second, optimum cooperation levels in cooperation for regional welfare and for competition are different due to the difference of cooperation effects in each motivation. Cooperation for competition requires higher cooperation level than cooperation in many situations. On the other hands, there are several situations where cooperation for regional welfare requires higher cooperation level than cooperation competition. Finally, the loss of average generalized in wrong cooperation change depending on the port situations. The loss is larger in areas where there is a higher gap of optimum cooperation level between motivations. Those findings can assist policymakers engaged in port management to realize port cooperation. Policymakers should consider port situations to realize effective port cooperation for each port. Additionally, policymakers can apply the knowledge about cooperation for regional welfare to cooperation for competition based on the difference by motivations obtained from this study.

Several issues remain for further research. The linear city, for example, does not completely represent port situation such that competition between port 1 and 3. One needs to apply actual situation as case study. The case study will make a concreate suggestion for cooperation. We cannot consider the decision of shipping lines in the model as well. Port cooperation contribute to the increase of bargaining power to increase of port of calls by shipping lines as Inoue (2018) suggested. The optimum cooperation can change on the decision of shipping lines. One needs to develop the extended model.

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