EXPLORING THE ESTABLISHED CONDITIONS OF DE-HUBBING MARITIME NETWORK

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Hub and Spoke network had been considered significant not only in maritime transport but also in air transport. In air transport, the partial or complete abandonment of a hub by the dominant carrier, known as "de-hubbing", implemented. As for maritime transport, de-hubbing have not implemented. The reason is that compared to air transport economy of density has a stronger influence on maritime transport. In some routes or conditions economics of scale does not work well and short lead time transport can be significant. The objective of this study is to explore the established conditions of the de-hubbing. The word "de-hubbing" is defined as the partial or complete abandonment of Hub and Spoke network and changed to use Point to Point network. To explore the conditions, bi-level optimization model is developed and applied to two simulations focused on network designing of shipping line. We find that de-hubbing can be realized in the area where it is difficult to collect cargo. Especially, in short distance transport, it is difficult to collect cargo and shipping lines prefer high frequency shipping by small ships. The possibility of de-hubbing is high.

Key Words : *de-hubbing, network design, maritime network, bi-level model*

1. BACKGROUND

In the late 19th century, Hub and spoke network (HS network) appeared as one of the transport network. In HS network, cargoes are concentrated in intermediate (air)port, called hub, and distributed into each destination (air)port ,called spoke. This cause congestion at hub and longer lead time than direct route. However, economy of scale by concentration make transport cost per unit lower. HS network had been considered significant not only in maritime transport but also in air transport. As for air transport, the partial or complete abandonment of a hub by the dominant carrier, known as "de-hubbing", implemented (Redoni et al 2012 and Bhadra 2009). One reason for de-hubbing is that Low Cost Carrier have become popular. Low Cost Carrier is point to point network (PP network) of which passengers are transported directly between origin airport and destination airport. PP network is superior to HS network in shorter lead time. In addition, Low Cost Carrier realize high frequency and low fare by saving operating cost (Kobayashi 2017). This makes PP network (Low Cost Carrier) more significant than HS network in some route and cause de-hubbing in air transport.

As for maritime transport, de-hubbing have not implemented. The reason is that compared to air transport economy of density has a stronger influence on maritime transport (Kobayashi 2017). Throughout maritime transport, ship size are increases year by year to achieve lower unit cost by economy of scale. However, some researchers prove that larger sized vessels are not always good. Tran and Hassis (2015) confirm by using multiple regression models whether five elements, which are total fleet capacity, average ship size, slot utilization, oil price and freight rate, have correlation between cost and profit of shipping line respectively. They concluded there is no evidence of the effect of ship size growth on the financial indicators. Fan and Luo (2013) mentioned bigger ships can decrease the benefits of expansion depending on demand. In short, economy of density on maritime transport does not work well in some conditions. Meanwhile, due to regulations within EU such as tariff procedure shorter lead time transports by high speed ships (Ro-Ro ship or ferry) are realized in

EU (Fujiwara 2014). According to the Eurostat database, short sea shipping within Europe consist of 271.0 million tonnes containers and Ro-Ro units 253.4 million tonnes in 2017. Those mean in some routes or conditions economics of scale does not work well and short lead time transport can be significant. In other words, in some conditions PP network can be more significant than HS network in maritime transport (de-hubbing).

The objective of this study is to explore the established conditions of the de-hubbing. The word “de-hubbing” is defined as the partial or complete abandonment of HS network and changed to use PP network. To explore the conditions, bi-level optimization model is developed. In the simulation, the model is applied to virtual areas to explore macro conditions in transport; navigation distance and cargo volume.

The rest of this paper is structured as follows. Section 2 include review of previous literatures related to de-hubbing. In Section 3, bi-level optimization model is developed. The model is applied to virtual area in Section 4. Finally, Section 5 conclude this study and show directions for further research.

2. LITERATURE REVIEWS

As far as authors know, there is no literature using the word “de-hubbing” in maritime transport. De-hubbing is mainly used on papers about air transport. In these papers, de-hubbing means just an abandonment of hub airport. Redoni et al. (2012) analyze the effect of de-hubbing between 1997 and 2009 in 37 airports. Demand of the airports decrease after de-hubbing. In the case where low-cost carriers are significantly involved, demand recover than the trend. Tan and Samuel (2016) develop a theoretical model to study the impact of de-hubbing on prices and quantities at the hub airport. They indicate airfares decrease when there is a low-cost carrier presence at the de-hubbing airport. Cattaneo et al. (2018) analyze the influence of flight network connectivity of airports on local economies by considering de-hubbing of Malpensa Airport.

Network design is an important factor for strategic decision-making level in shipping line (Meng et al. 2014). There are literatures about containership routing without using de-hubbing. Hsu and Hseih (2007) calculate optimal liner routing, ship size and sailing frequency based on a trade-off between shipping costs and inventory costs. As hub port charges decrease or the efficiency improve, shipping line tend to use the hub port. Ji et al. (2015) consider the ship routing optimization problem in a hub-and-spoke network through an improved genetic algorithm. They show that time deadline, containership capacity and cargo handling capacity of each port have significant influence on the total cost on the number of routes. According to Kim et al. (2019), shipping routing is affected by the sea freight rate, but is not strongly affected by the bunker price, chartering cost, or ship size. Some researchers construct models to solve several network problem. Song and Furman (2013) propose the model to solve practical maritime inventory routing problem. Bell et al. (2011) propose frequency-based maritime container assignment model and apply to assignment of full and empty containers. Bell et al. (2013) also propose cost-based maritime container assignment model and apply in the same way. Dekker (2014) solve the combined fleet-design, ship-scheduling and cargo-routing problem as a network designing. There are researchers who explain efficiency of specific routes. Lin and Chang (2018) analyze ship routing and freight assignment of the Northern Sea Route. They state shipping via the Suez Canal remains the most profitable shipping route for carriers but in several situations such as improved navigation skill, higher bunker price and so on Northern Sea Route can be an attractive route. Mulder and Kjetil et al. (2015) and Dulebenets (2018) analyze a shipping route with Emission Control Areas. Some researchers explore development of Maritime Silk Road (Jiang et al 2018 and Peng et al 2018). Jiang et al. (2019) analyze the network capacity performance on 706 ports and 2306 container liner routes along the Maritime Silk Road. They state transshipment capacity of hub ports improve the capacity performance of the port shipping network.

In addition, shipping line have to make a trade-off between the demand of shippers and operational cost when designing networks (Ducruet, C. and Notteboom, T. 2012). Several researchers analyze shipping networks affect behavior of shippers. Angeloudis et al. 2016 and Wang et al. 2014 analyze the effect of competition between several shipping lines to container flow by using game theory. Shibasaki and Kawasaki (2017) show the number of containers transshipped at Colombo Port increases while those of neighboring hub ports decreases as the transshipment time at Colombo Port decreases. They also point out the possibility of the drastic shift from an old hub to new one. Wang et al. (2013) analyze container flow in liner shipping network while considering the O–D transit time and maritime cabotage constraints. Talley (2014) states carrier, shipper and port have both direct and indirect effects on the choice. Kawasaki et al (2019) point out the importance to consider the several stakeholders involved maritime transport.

Based on the review of previous studies, network designing in maritime transport is affected by several conditions. No researchers explore the established conditions to realize de-hubbing in maritime transport. In addition, maritime transport is fairly complex since it involves several stakeholders. Especially, in network designing not only shipping line but also shipper should be considered.

3. MODEL DEVELOPMENT

In this study, bi-level optimization model is considered. As the upper decision makers, shipping lines try to minimize own profit. As the lower decision makers, shippers decide to use network based on own generalized cost. The case where generalized cost of shipper in PP network is lower than in HS network is regarded as a de-hubbing. The notations for the simulation model are as follows.

Notations

i,j	Port name ($i \neq j$, $i,j \ni$ origin, hub and destination)
k	Name of network system (Hub or Point to point)
GC_{ij}^k	Generalized cost of shipper of using network x in network k [USD/TEU]
Cs_{ij}	Cost of shipping company from port i to j [USD/month]
sc_{ij}	Ship cost [USD/day-times]
fc_{ij}	Fuel cost [USD/day-times]
pc_{ij}	Port charge [USD/times]
hc_i	Handling charge in port i [USD/TEU]
f_{ij}	Frequency from port i to j [times/month]
s_{ij}	Vessel size using from port i to j [TEU]
v_{ij}	Navigation speed from port i to j [knot]
d_{ij}	Navigation distance between port i to j [nm]
Q_{ij}	Total container cargo volume from port i to j [TEU/month]
q_{ij}	Cargo volume at one call from port i to j [TEU/times]
τ_{ij}	Freight rate from port i to j [USD/TEU]
L_i	Loading/unloading volume per hour in port i [TEU/hour]
T_i	Time to enter port which includes pilotage and waiting in anchorage [hour]
Wt_i	Waiting time of shipper in port i [day]
α	Value of time of shipper [USD/hour]
γ	The ratio of maximum carrying capacity
μ	The ratio to decide distance of hub port
δ_{ij}	The ratio of cargo in the other OD from port i to j

(1) Shipping line

The objective of shipping line is to minimize own cost in a given inputs. Shipping line decide ship size (s_{ij}), vessel speed (v_{ij}) and frequency (f_{ij}) in each route (from port i to port j). Equation 1 shows the cost of shipping company. The cost is calculated by the product of frequency of calls (f_{ij}) and shipping cost per call within the brackets. According to Hsu and Hseih (2007), monetary shipping costs can be divided into three parts; capital and operating costs, fuel costs and port charges. Capital and operating costs represent the total expenses paid for using the ship each day. In this study, they are renamed to ship cost (sc_{ij}) and consist of the chartering the ship, the ship operating cost including maintenance, repair costs and so on. Ship cost is spent on total voyage time. Total voyage time include navigation time which is calculated by navigation distance and navigation speed (d_{ij}/v_{ij}), time in port which means loading or discharge in port (q_{ij}/L_i) and the time to enter port which includes pilotage and waiting in anchorage (T_i). Fuel costs (fc_{ij}) are the expenses of the fuel consumption in the sailings. As Ronen (1982) and Wang and Meng (2012) shown, fuel consumption per day is the third power of navigation speed (v_{ij}). Navigation time (d_{ij}/v_{ij}) is multiplied. Port charges can be divided into the charge for the ship and the stevedoring charge. In this study the former is named port charge (pc_{ij}) and consists of a servicing the ship, including pilotage, towage and so on. It is paid twice at origin and destination port. The latter is named handling charge (hc_i) and is paid for cargo handling in the container yard. It is spent per cargo, so cargo volume per call (q_{ij}) is multiplied. There are several constrains to minimize own cost. Equation 2ensures shipping lines provide shipping capacity that exceeds total cargo volume (Q_{ij}). γ means maximum carrying capacity in the one call. Equation 3implies calculation of cargo volume per call (q_{ij}). δ_{ij} is the ratio of cargo in other OD. This is mainly used in cargo from hub to destination. δ_{ij} can express the ability to collect cargo in other word port competitiveness.

$$\min_{f_{ij},s_{ij},v_{ij}} Cs_{ij} = f_{ij}\left(sc_{ij}\cdot\left(T_i+\frac{q_{ij}}{L_i}+\frac{d_{ij}}{v_{ij}}+T_j+\frac{q_{ij}}{L_j}\right) + fc_{ij}\cdot v_{ij}^3\cdot\frac{d_{ij}}{v_{ij}}+2*pc_{ij} + \left(hc_i+hc_j\right)\cdot q_{ij}\right) \tag{1}$$

subject to:

$$\gamma\cdot f_{ij}\cdot s_{ij}\geq Q_{ij} \tag{2}$$

$$q_{ij} = \delta_{ij}\cdot Q_{od}/f_{ij} \tag{3}$$

Ship cost, fuel cost and port charge are depended on ship size. They are calculated as shown in Equation 4-6, respectively (Tran 2011, Kim et al 2019 and Gkonis and Psarafits 2009). BP means bunker price, in this study 385.5 USD/ton which is average in global 20 ports from 31st July 2018 to 30st August 2019 (sourced by Ship & Bunker).

$$fc_{ij} = BP \cdot (0.0392 \cdot s_{ij} + 5.582) \,/\, (5.4178 \cdot s_{ij}^{0.1746})^3 \tag{4}$$

$$sc_{ij} = 108.05 \cdot s_{ij}^{0.6257} + 0.948 \cdot s_{ij} + 4120 \tag{5}$$

$$pc_{ij} = 0.3936 \cdot (12.556 \cdot s_{ij} + 1087.2) + 5356 \tag{6}$$

(2) Shipper

In this study, generalized cost per day of shipper is calculated by time cost and monetary cost. Equation 7 and Equation 8 show generalized cost in PP network and HS network, respectively. Generalized cost in HS network is calculated by adding factors in hub port to in PP network. Wt_i means waiting time at port i such as container cut time and tariff procedure. $30/2f_{od}$ means average waiting time to vessel coming. Unit of frequency is ports of calls per month. 30 is multiplied. As other time factors, navigation time (d_{ij}/v_{ij}) and loading or discharge time (q_{ij}/L_i) are considered. As a monetary cost of shipper, freight rate (τ_{ij}) from shipping line is considered. This is calculated in Equation 9. This means shipping line decide freight rate not to be deficit. The situations where strong competition between shipping lies is occurred are assumed.

$$GC_{od}^{point} = \alpha\left(Wt_o + \frac{30}{2f_{od}} + \frac{q_{od}}{L_o} + \frac{d_{od}}{v_{od}} + \frac{q_{od}}{L_d} + Wt_d\right) + \tau_{od} \tag{7}$$

$$GC_{od}^{hub} = \alpha\left(Wt_o + \frac{30}{2f_{oh}} + \frac{q_{oh}}{L_o} + \frac{d_{oh}}{v_{oh}} + \frac{q_{oh}}{L_h} + \frac{30}{2f_{hd}} + \frac{q_{hd}}{L_h} + \frac{d_{hd}}{v_{hd}} + \frac{q_{hd}}{L_h} + Wt_d\right) + \tau_{oh} + \tau_{hd} \tag{8}$$

$$\tau_{ij} = \{min\, \tau_{ij} \,|\, Q_{ij} \cdot \tau_{ij} \geq Cs_{ij},\ \tau_{ij} \in \mathbb{N}\} \tag{9}$$

(3) Solution algorithm

In this study, bi-level optimization is considered. At the first stage, shipping lines decide the variables (vessel size, navigation speed and frequency) to minimize own cost in the each network. As for HS network, shipping line decide the variables from origin port to hub port and from hub port to destination port, respectively. In HS network, separate calculations are performed. Navigation speed can be calculated as Equation10-12. Fuel cost is included in the denominator. This means shipping line reduce navigation speed in high bunker price.

$$\min_{f_{ij},\, s_{ij},\, v_{ij}} Cs_{ij} \quad \text{where } sc(s_{ij}) > 0 \text{ and } fc(s_{ij}) > 0 \tag{10}$$

$$\frac{\partial Cs_{ij}}{\partial v_{ij}} = \frac{f_{ij} d_{ij}}{v_{ij}^2}\left(2 \cdot fc(s_{ij}) \cdot v_{ij}^3 - sc(s_{ij})\right) \tag{11}$$

$$v_{ij} = \left(\frac{sc(s_{ij})}{2 \cdot fc(s_{ij})}\right)^{\frac{1}{3}} \tag{12}$$

In the second stage, shipper calculate own generalized cost based on shipping lines' decisions and comparison of generalized costs is performed. For all inputs, the bi-level optimization is performed and established conditions of de-hubbing are derived. Fig. 1 shows the soulition algorithm.

4. Simulation result

(1) Input

As an input, one origin port, two destination ports and one hub port are considered. Calculations are performed by changing two variables distance and cargo

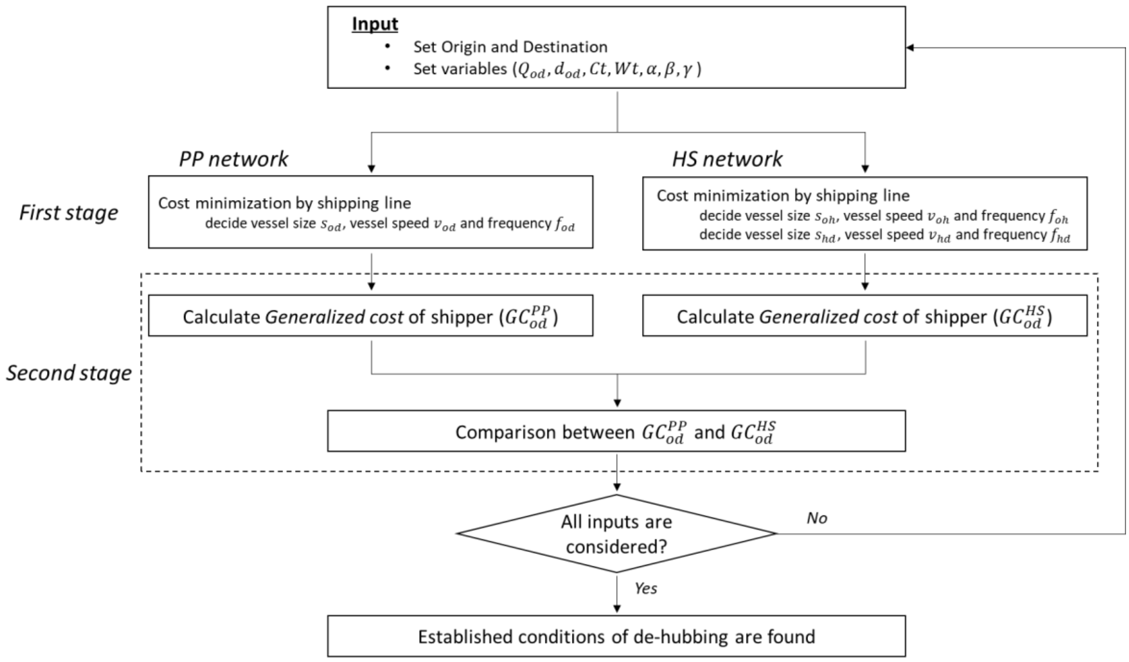


Fig. 1 Solution Algorithm

volume of these ports. One destination port (destination 1) is considered three cases; short case ($d_{o1} = 2000\ nm, Q_{o1} = 2500\ TEU$), middle case ($d_{o1} = 5000\ nm, Q_{o1} = 2500\ TEU$) and long case ($d_{o1} = 8000\ nm, Q_{o1} = 2500\ TEU$). In the each cases, the two variables of the other destination port (destination 2) are changed as shown Equation 13 and 14. Comparison between generalized costs from origin port to destination 2 in PP network and HS network is done to explore de-hubbing. Equation 15 means distance from origin port to hub port is determined by the distance between origin port and the destination port closer to origin. In this study, the ratio (μ) has three values (1/2, 1/3, 1/4) shipping lines can decide one from them. Fig. 3 shows simulation image.

$$d_{o2} = \{100 * n_1 | 1 \leq n_1 \leq 100,\ n_1 \in \mathbb{N}\} \tag{13}$$

$$Q_{o2} = \{500 * n_2 | 1 \leq n_1 \leq 20,\ n_1 \in \mathbb{N}\} \tag{14}$$

$$d_{oh} = \mu * min\{\ d_{o1},\ d_{o2}\} \tag{15}$$

Table 1 shows other variables in this model. Those variable are sourced by Wang and Meng (2012) and WAVE (2011). As for ship size (s_{ij}), shipping lines can decide one ship size of 15 types from 1000 TEU to 15000TEU. In the route from origin to hub, shipping lines can choose 7 types from 1000 TEU to 7000 TEU.

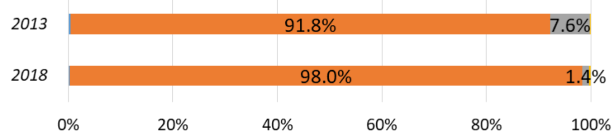
(2) Result

Fig. 4 shows the simulation results of three cases about destination 1 (short, middle and long). They are almost same results. This means positions of ports don't influence generalized cost of shippers in other ports. As shown Fig. 5, if collecting cargo volume is changed at the hub, results are changed. This means cargo volume of other ports influence generalized cost of shippers in other ports. This is because generalized cost of shippers depend on sailing information such as frequency and ship size, and they depend on not positions but cargo volume of other ports.

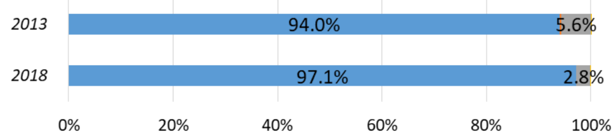
Those results are changed at the two boundaries; 3500 TEU (cargo volume) and 1200 nm (distance). As for cargo volume, within 3500 TEU generalized costs of shippers in PP network are better. This is due to collecting cargo volume at hub port (δ_{hd}). Collecting cargo volume is decided by product of cargo volume between origin and destination. In the low cargo volume, collecting cargo volume at hub is small and economy of scale at hub does not work well. As shown in Fig. 5 (b) and (c), if collecting cargo volume improve, economy of scale work and generalized cost in HS network improve. This means de-hubbing can be realized in the areas where collecting cargo volume is small such as short distance between hub and destination.

As for distance, within 1200 nm generalized costs of shippers in PP network are better in some points. This is because high frequency shipping by small ships are realized. In short distance, total voyage time is short. So, costs of using small ships whose fuel cost per TEU is higher and fixed cost such as ship cost is lower are lower than large ships whose fuel cost per TEU is lower and fixed cost is higher. This means in short distance transport, de-hubbing can be realized.

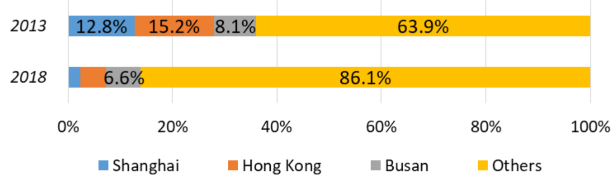
Fig. 2 shows the ratio of ports where cargo from Japanese ports was first shipped. The case where destination and first port is same means the cargo is directly transported. In other case, the cargo is transshipped. As showns those, in the routes between Japan and China de-hubbing the ratio of trannshiped is decreasing. In short transport de-hubbing proceeds.



(a) Destination : Hong Kong port



(b) Destination : Shanghai Port



(c) Destiantion : Other Chinese ports

Fig. 2 The ratio of ports where cargo from Japanse ports was first shipped

Source : MLIT in Japan

Table 1 Input parameters in simulation

		Origin	hub	Destination
Handling charge in port i [USD/TEU]	hc_i	60	100	60
Loading/discharge volume per hour in port i [TEU/hour]	L_i	100	100	150
Time to enter port [hour]	T_i	8	8	12
Waiting time of shipper in port i [day]	Wt_i	2	-	1
Value of time of shipper [JPY/hour]	α	2200		
The ratio of maximum carrying capacity	γ	0.7		

※ 1 USD = 106.3 JPY average 31st July 2018 to 30st August 2019

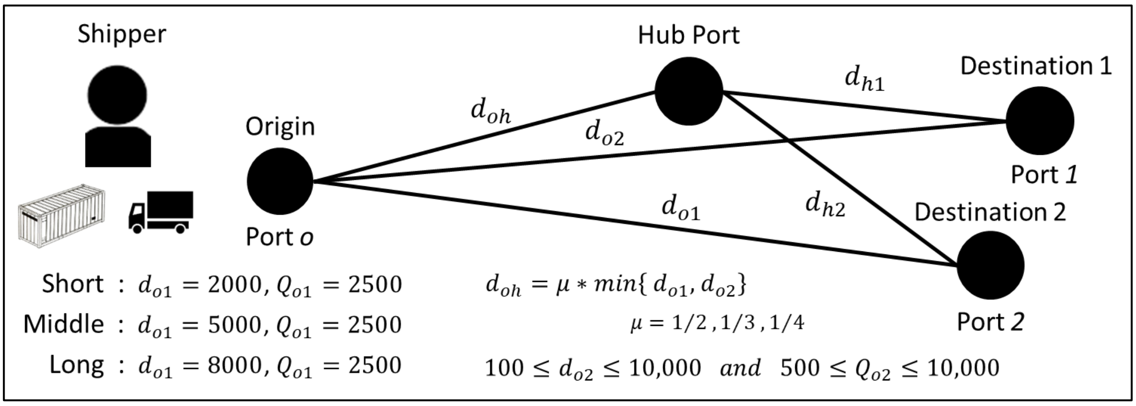
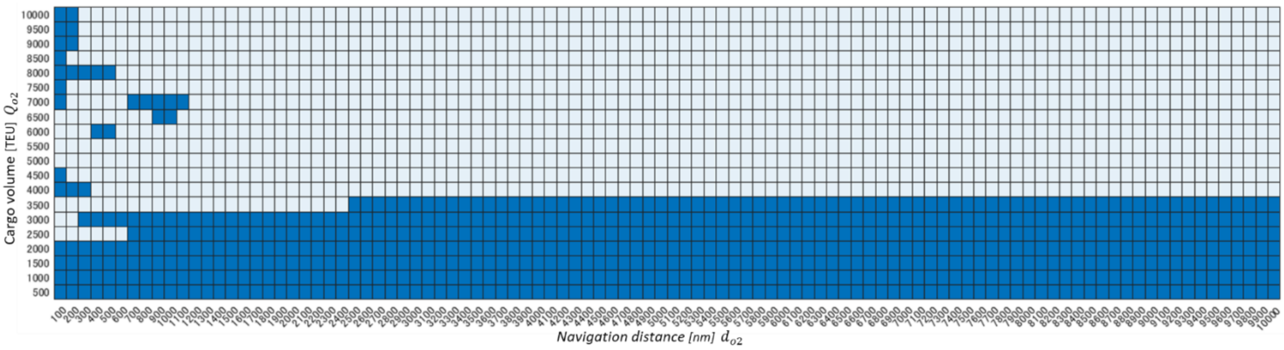
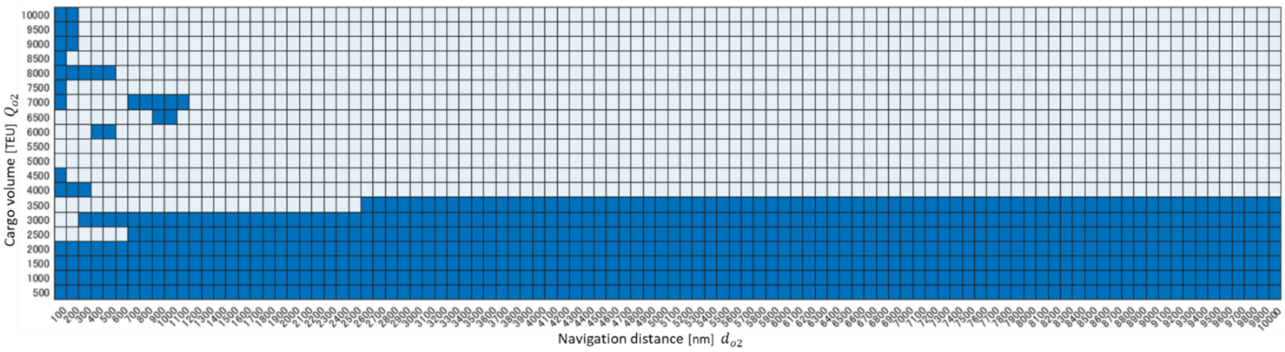


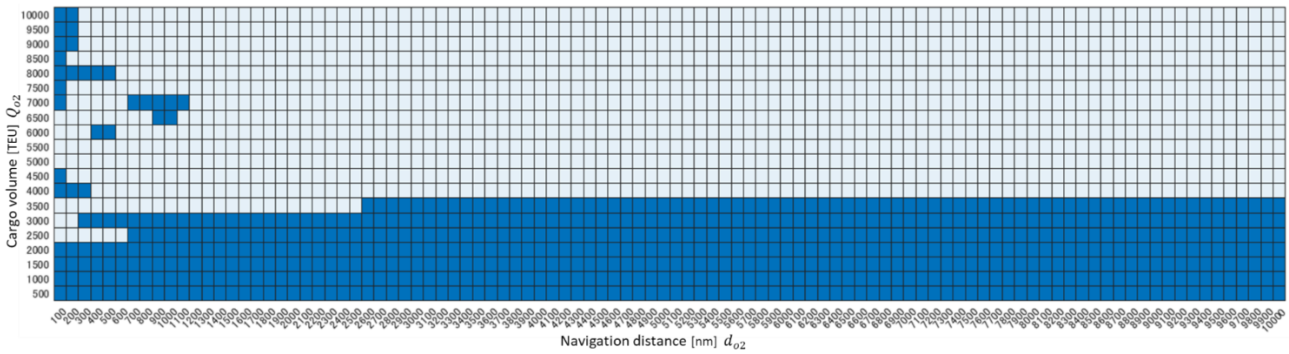
Fig. 3 Simultaion images



(a) Short case($d_{o1} = 2000\ nm, Q_{o1} = 2500\ TEU$), $\delta_{hd} = 3$



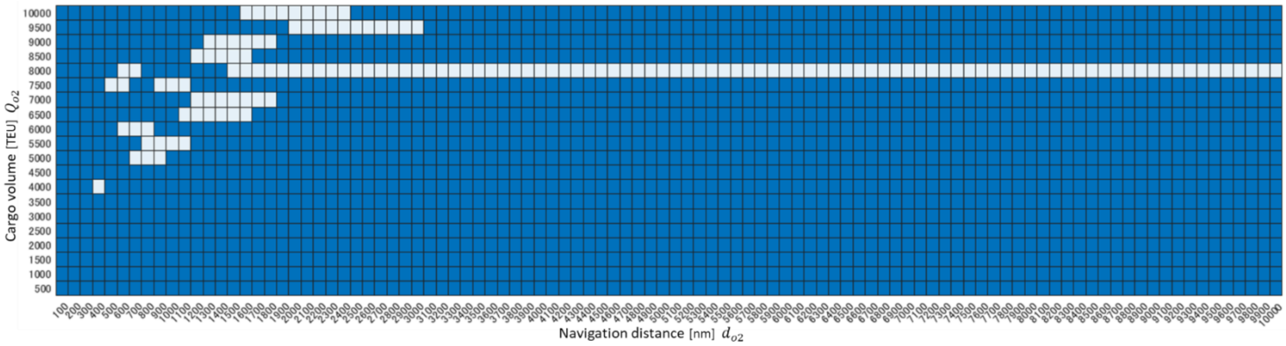
(b) Middle case($d_{o1} = 5000\ nm, Q_{o1} = 2500\ TEU$), $\delta_{hd} = 3$



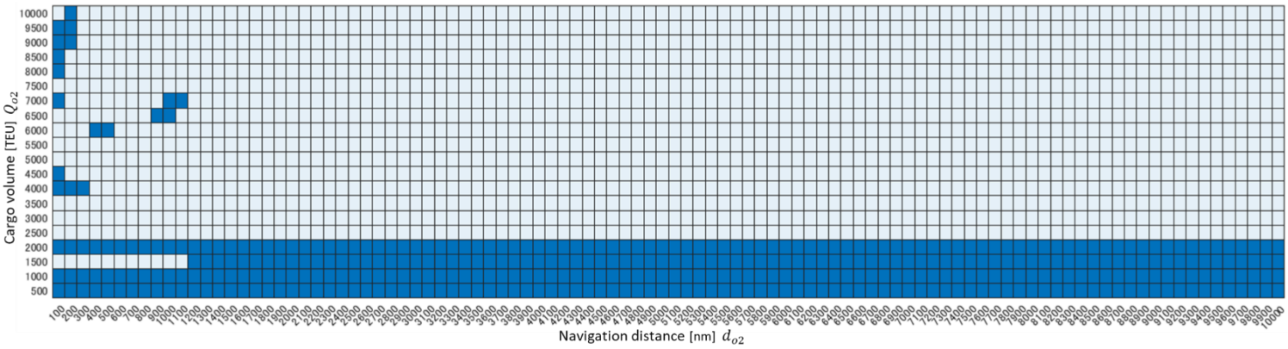
(c) Long case($d_{o1} = 8000\ nm, Q_{o1} = 2500\ TEU$), $\delta_{hd} = 3$

※ ■ $GC_{o2}^{hub} > GC_{o2}^{point}$, □ $GC_{o2}^{hub} < GC_{o2}^{point}$ (Blue is better for PP)

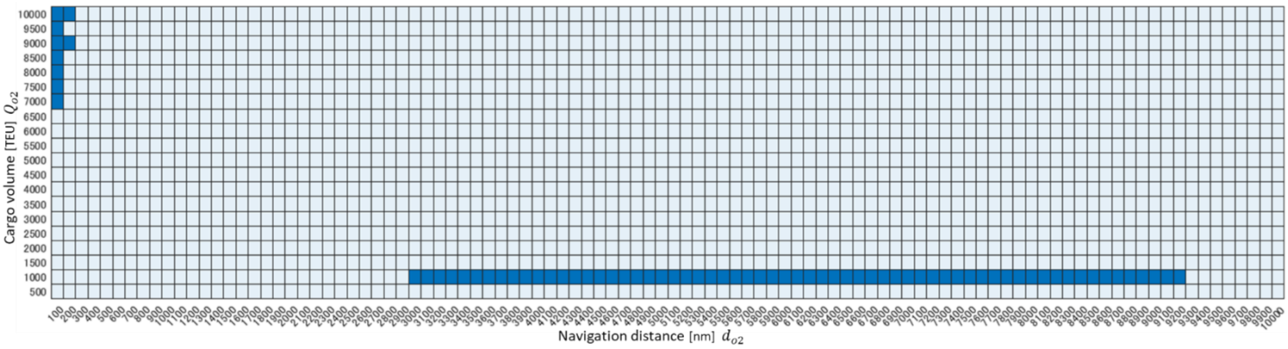
Fig. 4 Simulation results of three cases (GC_{o2}^{hub} and GC_{o2}^{point})



(a) Short case, $\delta_{hd} = 1$



(b) Short case, $\delta_{hd} = 10$



(b) Short case, $\delta_{hd} = 10$

※ ■ $GC_{o2}^{hub} > GC_{o2}^{point}$, □ $GC_{o2}^{hub} < GC_{o2}^{point}$ (Blue is better for PP)

Fig. 5 Simulation results of chaning cargo volume (GC_{o2}^{hub} and GC_{o2}^{point})

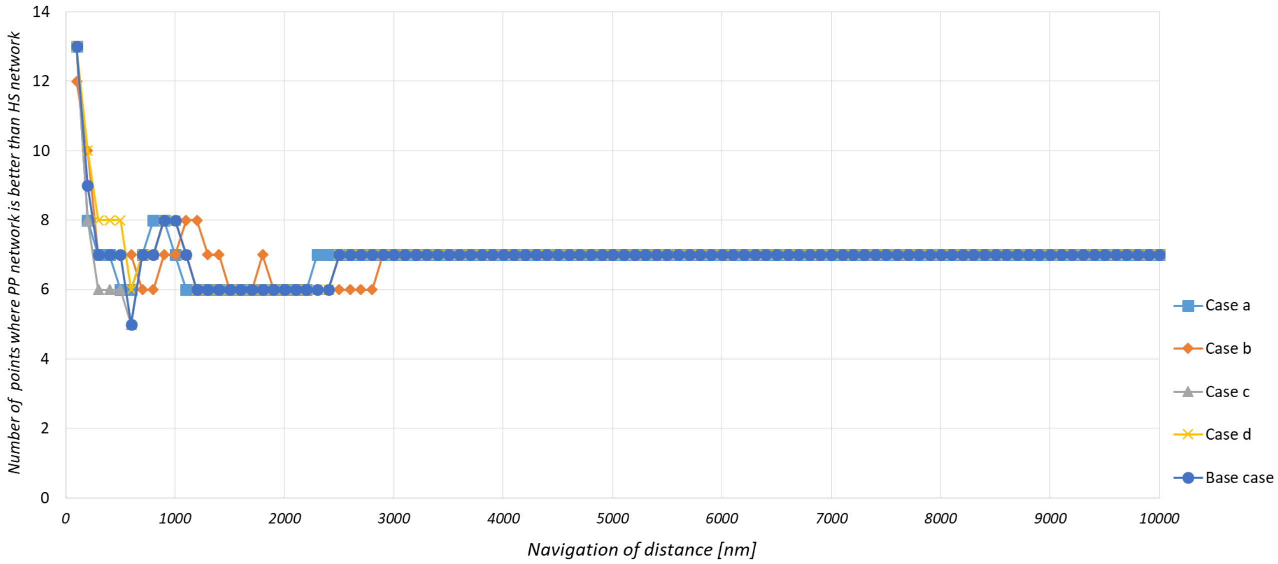


Fig. 6 Result of sensitivity analysis

(3) Sensitivity Analysis

As a sensitivity analysis, we focus on two parameters; bunker price and value of time. Table 2 shows the values of cases which are done as a sensitivity analysis. Bunker price is increasing year by year. However, fuel consumption can be improved with the development of technology. So, two cases where bunker price increase and decrease are considered. As for value of time, it is depends on shippers. This means value of time can be higher and lower. Two cases about value of time are considered. All cases are applied to short case and $\delta_{hd} = 3$. Base case means the case where variables in Table 1 is applied to short case and $\delta_{hd} = 3$.

Table 2 Values about sesitivity analysis

Case a	Case b	Case c	Case d
Bunker price		Value of time	
500	200	3300	1600

As shown Fig. 6, in short case within 3000 nm, results are fluctuating. But, there is no superior case for de-hubbing. This means poissibilty of de-hubbing depends on variables. Established conditions of de-hubbing is different from the araeas. To estimate the more detail conditions, this model shoud be applied to real case. This would be a future study.

5. CONCLUSION

In this study, bi-level optimization model to estimate established conditions of de-hubbing is constructed. The word "de-hubbing" is defined as the partial or complete abandonment of HS network and changed to use PP network. The model is applied to virtual area. The case where generalized cost of shipper in PP network is lower than in HS network is regarded as a de-hubbing.

Through this study, the followings are clarified. Positions of ports don't influence generalized cost of shippers in other ports. Cargo volume of ports influence generalized cost of shippers in other ports. Collecting cargo volume at hub port is important for de-hubbing. Especially, in short distance transport within 1200 nm, since distance between hub and destination is short, it is difficult to collect cargo. In additions, costs of using small ships whose fuel cost per TEU is higher and fixed cost such as ship cost is lower are lower than large ships whose fuel cost per TEU is lower and fixed cost is higher. Shipping lines prefer high frequency shipping by small ships. This makes possibility of de-hubbing in short transport higher.

This model is only applied to virtual case. The results only show the possible area of de-hubbing. To show detail conditions, it is needed to apply this model to real case such as between China and Japan; within asia.

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