

Container Cargo Simulation Modeling for Measuring Impacts of Infrastructure Investment Projects in Pearl River Delta

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Abstract: In the Pearl River Delta (PRD), there is severe competition between container ports, particularly those in Hong Kong, Shenzhen, and Guangzhou, for collecting international maritime container cargo. In addition, the second phase of the Nansha terminal in Guangzhou's port and the first phase of the Da Chang Bay container terminal in Shenzhen opened last year. Under these circumstances, there is an increasing need to quantitatively measure the impact these infrastructure investments have on regional cargo flows. The analysis should include the effects of container terminal construction, berth deepening, and access road construction. The authors have been developing a model for international cargo simulation (MICS) which can simulate the movement of cargo. The volume of origin-destination (OD) container cargo in the East Asian region was used as an input, in order to evaluate the effects of international freight transportation policies. This paper focuses on the PRD area and, by incorporating a more detailed network, evaluates the impact of several infrastructure investment projects on freight movement.

Keywords: logistics; simulation modeling; cargo container; infrastructure investment

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1 Introduction

During the past decades, Asian economies have achieved great development. In particular, called as 'world's factory', China imports a huge amount of raw materials from overseas, and exports the products to the world everyday. China now ranks third in terms of trade amount, which earned 2 174 billion US dollars in 2007, behind U.S. and Germany. Since 1999, the growth of trade amount always surpasses that of nominal GDP, except in 2001 when world trade temporarily shrunk due to the event of the 9-11. Now, Chinese trade amount keeps a pace to be tripled during five years. Consequently, Asian ports including Chinese ports are also becoming the busiest ports in the world. In terms of container cargo throughput, 20 of the world's top 30 container ports in 2007 are located in Asia including nine Chinese ports. In particular, Shanghai, Hong Kong, Shenzhen together with Singapore are the top four ports in the world. In accordance with this, there are heavy investment at a lot of Chinese ports in order to improve their infrastructure and facilities and to construct new terminals and berths.

As a matter of course, their main purpose for investment might have been to cope with the drastic increase in trade amount and cargo volume. However, it is also obvious that port investment itself affects the cargo flow including the

volume handled at the port in question, because it improves efficiency and convenience of the port. In particular, because the ports in mainland China were behind in their growths compared with their surrounding ports such as Hong Kong, Kaohsiung (Chinese Taipei), and Busan (South Korea), their expectancies to catch up with these surrounding ports and to become the regional dominant port might have accelerated the investments. As results, some of them including port of Shanghai and Shenzhen now take positions as regional center ports and threaten their rivals. The year 2007 could be memorable that container throughput in port of Shanghai surpassed that in port of Hong Kong and took the first place among Chinese ports. Although heavy economic recession had rushed into 2008 due to financial crisis of the U.S., a ranking of container throughput in Chinese ports has not changed.

In the Pearl River Delta (PRD), there are many container terminals. Kwai Tsing container terminal (CT) handles about two-thirds of the total containers at the port of Hong Kong, while at the port of Shenzhen there are four major terminals such as Yantian, Shekou, Chiwan, and China merchants (Shenzhen). In Guangzhou, Nansha CT had opened in 2004 in Nansha economic and technological development zone along coastal area, in addition to existing river terminal along Pearl River such as Huangpu Xinganag terminal. Other municipal cities in the PRD such as Zhongshan and Zhuhai also have their own container terminals. These terminals are competing to collect container cargo originating from the PRD area where large amounts of

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goods for export are daily produced. Under this severe competitive condition, in 2007, the 2nd phase of Nansha container terminal and the 1st phase of Da Chan Bay CT (DCB-CT) in Shenzhen had opened. In particular, DCB-CT is the fifth container terminal in Shenzhen, and there are wide concerns that how many containers it can successfully attract.

The authors have been developing a model which can simulate the movement of international container cargo with OD volume of container cargo as a given input, focused in East and Southeast Asian region, in order to evaluate the impact of international freight transport policy, such as port investment as well as improvement of connection between port and road.

In this paper, the authors incorporate detailed network of the PRD area into the existing model, in order to simulate international cargo movement in this area and evaluate the impacts of the infrastructure investment such as construction of new container terminal and expressway.

2 Container terminals in Pearl River Delta

2.1 Competition of container terminals in the Pearl River Delta

Major CTs in the PRD are Kwai Tsing (Hong Kong), Yantian, Shekou, Chiwan, and China merchants (Shenzhen), Nansha and Huangpu (Guangzhou). In the past ten years, container throughputs of each terminal were increasing steadily; while Kwai Tsing CT kept its first position, the growth rates in CTs of Shenzhen and Guangzhou surpassed that in Kwai Tsing CT. In addition, a large number of other container terminals and multipurpose terminals in the PRD have handled container cargos, connected by barges with the above major CTs. Besides the port of Zhongshan and Zhuhai (Jiuzhou and Gaolang terminal), all of the other cities in the PRD also have container terminals, i.e. Jiangmen (596 000 TEU in 2007; all of the numbers of container throughputs are quoted from China Port Yearbook.) and Xinhui (118 740 TEU) terminal in Jiangmen City, Nanhai (260 000 TEU) terminal in Foshan city, Huizhou (166 100 TEU), Dongguan (221 200 TEU), and Zhaoqing (261 700 TEU). Most of these feeder terminals are also enjoying stable growth in container throughputs lately.

On the other hand, the handling amounts in other terminals and mid-stream operation (i.e., loading and unloading containers at a containership from/to barges at sea) at the port of Hong Kong are stagnating or decreasing, supposedly affected by the development and growth of the above major terminals in Shenzhen and Guangzhou. In addition, in some of these major terminals such as Shekou (in Shenzhen) and Huangpu (in Guangzhou), the growth rates are slowing down. In this way, although the total

volume of container cargo originated from the PRD area still keeps on increasing, it is no doubt that competition among CTs becomes severer.

2.2 Development of Da Chan Bay container terminal and neighboring infrastructure

Under the circumstances, Da Chan Bay (DCB) CT had opened its first two container berths with -15.5 m depth on December 2007 as the fifth CT in Shenzhen City. The first phase terminal of this CT is operated by Modern Terminals Ltd. (MTL), one of the major operators in port of Hong Kong as well as Hutchison Port Holdings (HPH). In the near future, five more berths are planned to be added during the first phase; moreover, 22 berths with -18 m depth at maximum are ultimately planned by the fourth phase.

DCB-CT is located in the Western Shenzhen Port area and at a mouth of Pearl River as well as Shekou, Chiwan and China merchants CT. It is located 10km north away from these other CTs, outside the special economic zone of Shenzhen city (in Bao'an district), in-between Guangzhou city and Hong Kong/Shenzhen area. It is also 10km away from Shenzhen international airport; therefore, it might potentially be a hub for sea-and-air transport. As above, its location is more advantageous compared with Yantian International CT, the largest CT of Shenzhen city (at east coast of the city). In addition, Hong Kong-Shenzhen Western Corridor had opened on July 2007, which is the fifth land border between Hong Kong and Mainland China. This corridor straightly connects the city center of Hong Kong and DCB-CT.

Meanwhile, there are also some concerns. The greatest concern is that DCB-CT is a very latecomer. As described in the previous section, CTs' competition in the PRD has become severer. Because the terminal operation industry has great economy of scale that the handling cost per container decreases as the number of containers increases, it is highly disadvantageous to the latecomer. Furthermore, the second phase of Nansha terminal in Guangzhou also opened in the same year, and most of other terminals have extension plans respectively as well. Another concern is whether it can keep the water depth of berths and channels deep enough to accommodate larger containerships sailing on trunk route (i.e., long distance route connecting with North America or Europe), not only feeder transport in the PRD. This is a common problem among terminals in the PRD (except Yantian International CT which is located at the South Sea); therefore, Shenzhen city government is bound to maintain the channel (Tonggu Channel). At all events, there is increasing needs to quantitatively measure the impacts of these infrastructure investments, including container terminal construction, channel dredging and berth deepening, and access road construction and improvement, on regional cargo flows.

3 Models for policy simulation

3.1 Model structure

3.1.1 Overview

Until now, the authors have developed a model to reproduce the international maritime container cargo flow between all of the Japanese container ports, the major ports of East Asia, and other areas, as well as the land transport of container cargo within Japan, when the OD cargo flows between regions are given. However, the interest of the earliest model (Ieda *et al.*, 2000) is only cost minimization behavior of either carriers or shippers; in addition, there is no consideration of interaction between them. In the later model described in Shibasaki *et al.* (2005) and Shibasaki *et al.* (2007), although interaction between carriers and shippers is considered, it is not sufficient; for example, cost

minimization is only considered as behavior of carriers, not profit maximization, and transport network of shippers' and carriers' model is the same.

Therefore, the authors revised the above model to meet theoretical consistency to oligopolistic international maritime shipping market and, at the same time, to improve model accuracy, under the condition that it can reproduce well international container cargo flow on real huge transport network. A structure of the revised model is shown in Fig.1. Shippers and carriers are assumed to independently optimize their different objectives or objective functions, and, as a result, reach to a Nash equilibrium under which they cannot improve themselves each other without changing a principle of the other party's behavior.

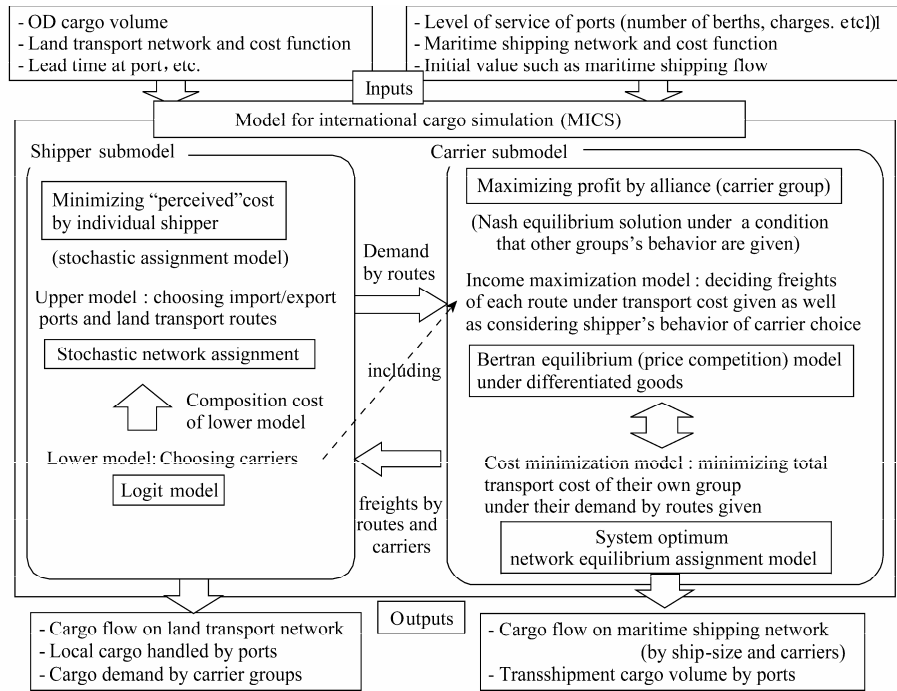


Fig.1 Entire structure of the developed model

3.1.2 Shipper sub-model

Shippers are assumed to select port for export and import, carriers for ocean-going shipping, and routes for land transport, in order to minimize their "perceived generalized cost" individually including transport cost, time, and other various unobservable factors. Thus, a stochastic model, which can consider such unobservable factors as error terms, is applied. Concretely, a nested logic type simulation model is adopted; choose port and land route at the upper level and carrier at the lower level. In the upper choice level, Dial (1971) assignment, i.e. a typical stochastic network assignment methodology, is adopted instead of a plain logic model, because it does not need listing alternative routes beforehand unlike logic model and therefore is suitable for the assignment under such a huge network like this model.

In the lower choice level of carrier selection, a simple logic model is applied and log sum values of the model are incorporated into the transport cost of the upper level model.

1) Upper level model for export/import port and land route selection

$$f_{rsk} = Q_{rs} \cdot \frac{\exp(-\theta \cdot c_{rsk})}{\sum_{k \in K_{rs}} \exp(-\theta \cdot c_{rsk})} \quad (1)$$

$$c_{rsk} = \sum_{a \in k} \Lambda_a + \sum_{b \in k} C_{L_b} + \sum_{i \in k} C_{P_i} \quad (2)$$

$$\Lambda_a = -\frac{1}{\theta} \cdot \ln \sum_{g \in G} \exp(-\theta \cdot C_{M_{ag}}) + \zeta \quad (3)$$

$$C_{L_b} = C_{L_{cost_b}} + v_{t_{shpr}} \cdot C_{L_{time_b}} \quad (4)$$

Here, f_{rsk} refers to cargo volume of path k for OD-pair rs , Q_{rs} refers to OD cargo volume between r and s , θ refers to variance parameter on Gumbel distribution, c_{rsk} refers to transport cost of path k for OD-pair rs , K_{rs} refers to choice set of path for OD-pair rs , A_a refers to expected minimum cost (log sum values) of maritime shipping link a included in path k , C_{L_b} refers to generalized transport cost of land transport link b included in path k , C_{P_i} refers to generalized cost of intra-port link i included in path k , $C_{M_{ag}}$ refers to generalized cost of carrier group g in maritime link a , G refers to carrier group set (here, 9 groups), ζ refers to

adjustment parameter so that expected minimum cost could be not negative, $C_{L_{cost_b}}$ means monetary cost of link b , $v_{t_{shpr}}$ refers to value of time for shippers, $C_{L_{time_b}}$ means transport time of link b .

Fig.2 shows a typical network of the shipper sub-model, especially focusing in the port. In a carry-in link and carry-out link of intra-port links, lead time when export and import cargo is considered as a link cost. On the other hand, in a transshipment link, transshipment cost and time when cargo is transshipped owing to shippers are considered as a link cost. (Please note that transshipment owing to carriers is considered in the carrier sub-model.)

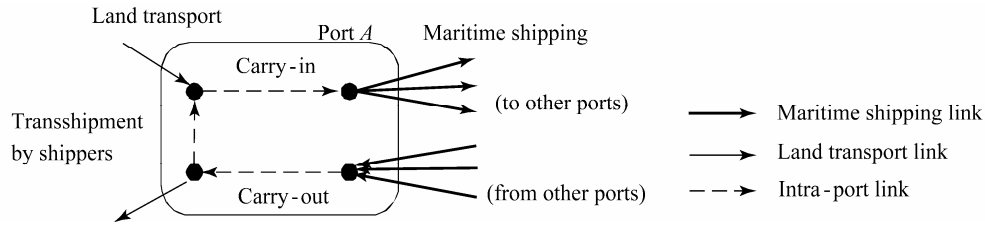


Fig.2 Intra-port network of the shipper sub-model

2) Lower level model for carrier selection

$$q_{ag} = d_a \cdot \frac{\exp(-\theta \cdot C_{M_{ag}})}{\sum_{g \in G} \exp(-\theta \cdot C_{M_{ag}})} \quad (5)$$

$$d_a = \sum_{rs \in \Omega} \sum_{k \in K_{rs}} \delta_{rsk}^a \cdot f_{rsk}, \quad \forall a \in A \quad (6)$$

$$C_{M_{ag}} = p_{ag} + v_{t_{shpr}} \cdot C_{M_{time_{ag}}} \quad (7)$$

Here, q_{ag} refers to cargo volume of carrier group g in maritime route a , d_a refers to cargo demand of maritime route a , if link a is included in path k for OD-pair rs , $\delta_{rsk}^a=1$, otherwise $\delta_{rsk}^a=0$, Ω refers to OD pair set, A refers to maritime route set (because maritime route is defined by combination of a port for export and a port for import, the number of routes is equal to the number of ports multiplied by the number of ports minus one), p_{ag} refers to freight for route a proposed by group g , $C_{M_{time_{ag}}}$ refers to total transport time for route a of group g .

3.1.3 Carrier sub-model

Carriers are assumed to maximize their net profits by making alliance of ocean-going shipping, by determining freights by shipping routes and transport patterns of international maritime shipping including sizes of containership and choice of transshipment ports.

$$\pi_g = \sum_{a \in A} p_{ag} \cdot q_{ag}(p_{a1}, \dots, p_{ag}, \dots, p_{aG}) - \sum_{v \in V} x_{vg} \cdot t_{vg}(x_{11}, \dots, x_{vg}, \dots, x_{VG}) \quad \forall g \in G \quad (8)$$

$$\text{s.t.} \quad \max_{p,x} \pi_g \quad (9)$$

where, V is link set of maritime shipping network, x_{vg} is cargo flow of link v of group g , and t_{vg} is link cost function of link v of group g .

Eq.(8) represents net profit is defined as total income minus total cost. Normally, Eq.(9) is analytically solved that partial differentiation of Eq.(8) with respect to x and p should be zero (i.e., $\frac{\partial \pi_g}{\partial x} = 0$ and $\frac{\partial \pi_g}{\partial p} = 0$); however, it is indifferentiable. Therefore, a model of total income maximization and total cost minimization are independently calculated to obtain a Nash equilibrium solution among these two models by convergence calculation.

1) Income maximization model

$$\begin{aligned} \max_p \sum_{a \in A} p_{ag} \cdot q_{ag}(p_{a1}, \dots, p_{ag}, \dots, p_{aG}) \quad \forall g \in G \Leftrightarrow \\ \max_p p_{ag} \cdot q_{ag}(p_{a1}, \dots, p_{ag}, \dots, p_{aG}) \quad \forall g \in G, \forall a \in A \end{aligned} \quad (10)$$

In this model q_{ag} is determined by Eq.(5).

The revenue of each alliance is maximized by routes (expressed as a in Eq.(10)) consisting from one port for export to another port for import on the sea, by determining their freight of the route reflecting other carriers' freights and shippers' behavior of carrier choice as described in 3.2.2 (the lower level of shippers choice model). This model is a certain type of price competition model or Beltran-Nash

Equilibrium model in oligopolistic market of differentiated goods. Concretely, Eq.(10) is solved by each route and each alliance as follows.

$$\frac{\partial \{p_{ag} \cdot q_{ag}(\bar{p}_{a1}, \dots, p_{ag}, \dots, \bar{p}_{aG})\}}{\partial p_{ag}} = 0 \quad (11)$$

When $l_{ag} = \frac{\exp(-\theta \cdot C_{M_{ag}})}{\sum_{g \in G} \exp(-\theta \cdot C_{M_{ag}})}$ is not zero, Eq.(11) is deformed as follows by substituting Eq.(5).

$$l_{ag} + \frac{1}{\theta \cdot p_{ag}} - 1 = 0 \quad (12)$$

2) Total cost minimization model

The transport cost of each alliance is minimized in total for the entire maritime shipping network; therefore, the system optimum (SO) assignment is adopted by alliance. Concretely,

$$\min \sum_{v \in V'} x_{vg} \cdot t_{vg}(x_{v1}, \dots, x_{vg}, \dots, x_{vG}) \quad \forall g \in G \quad (13)$$

The network structure of the total cost minimization model is shown in Fig.3. Because the network structure and cost function of each link are similar to the previous model described in Shibasaki *et al.* (2005) and Shibasaki *et al.* (2007), the detailed explanation of them are skipped in this paper. Only a brief description of basic concept is shown as follows.

Cost function of each link is basically defined as summation of monetary cost and time cost per unit (TEU). Here, time cost is calculated by multiplying transport time by money-cost conversion factor. The reason why time cost is also included besides monetary cost is that some implicit costs exist such as insurance is considered better assuming proportional to transport time.

Some of link in the network shown in Fig.3 has flow-dependent (FD) cost function. For example, in a

cruise link connecting ports, in addition to cruise cost and time, expected waiting time cost related with frequency of service is also considered. As container flow in the questioned link increases, frequency of service increases and expected waiting time is shorter; therefore, the link cost also becomes smaller. This represents an economy-of-scale type FD cost function. On the contrary, in an arriving and departing link, there considered berth congestion that as the number of vessels arriving into/departing from ports increases, waiting time to arrive into or depart from ports also increases. This is a diseconomy-of-scale type FD cost. Methodologies for network equilibrium assignment with FD link cost are stated in many textbooks, starting with Sheffi (1985). A unique solution can be obtained if all of FD link cost functions are diseconomy-of-scale type; however, since there are economy-of-scale type FD link cost functions in this model, many equilibrium solutions will be obtained. Therefore, the authors input initial data representing actual condition, and obtained an equilibrium solution under a condition when starting from the actual condition.

Another difficulty is mutual interference between link cost functions of the network. For example, because terminal cost of the port is fixed, cost per TEU is dependent on the total number of containers handled in the port. The total amount of containers is defined as summation of flows in all of unloading and loading links. Specifically, the cost function of each unloading/loading link depends on not only the flow in the questioned link, but also those in other unloading/loading links. Mutual interference also exists among carrier groups. Because all of the terminals are assumed for common use, congestion costs when containerships are arriving and departing are common among them. In order to solve these interference problems, the authors adopted a relaxation method that only focuses on the influence of the flow in the questioned link, although the speed of convergence calculation becomes slow.

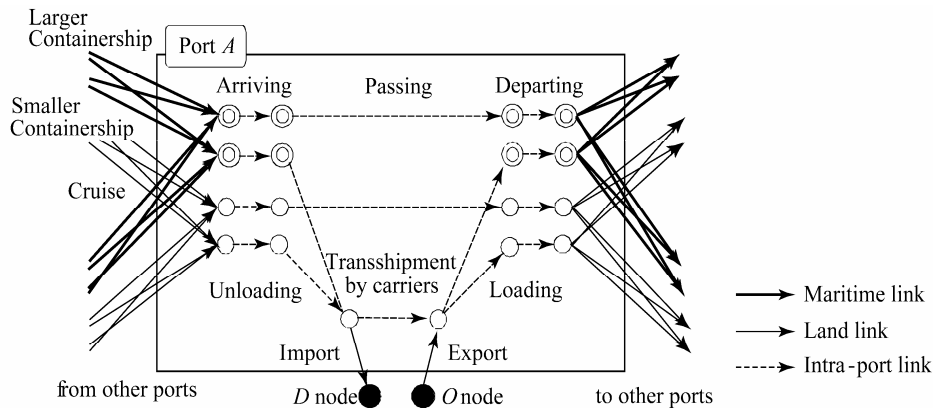


Fig.3 Network of the carrier's total cost minimization model

3.2 Model calculation

3.2.1 Convergence calculation

A flowchart of the entire model calculation is shown in Fig.4. The model contains several convergence calculation steps. In addition to the two types of convergence calculation shown in the figure, both models of income maximization and total cost minimization of carriers also include convergence calculation respectively; therefore, four types of convergence calculation in total are hierarchically embedded in the model. An iterative calculation between 2)

and 3) shown in the figure is aimed to obtain a Nash equilibrium in terms of carrier behaviors between income maximization including carrier choice behavior of shippers and total cost minimization, supposing a short-term optimization behavior. On the other hand, an iterative calculation between 1) and the above short-term optimization model of carriers, i.e. 2) and 3), assumes a mid-term optimization behavior, obtaining a Nash equilibrium between port choice behavior of shippers and net profit maximization behavior of each carrier.

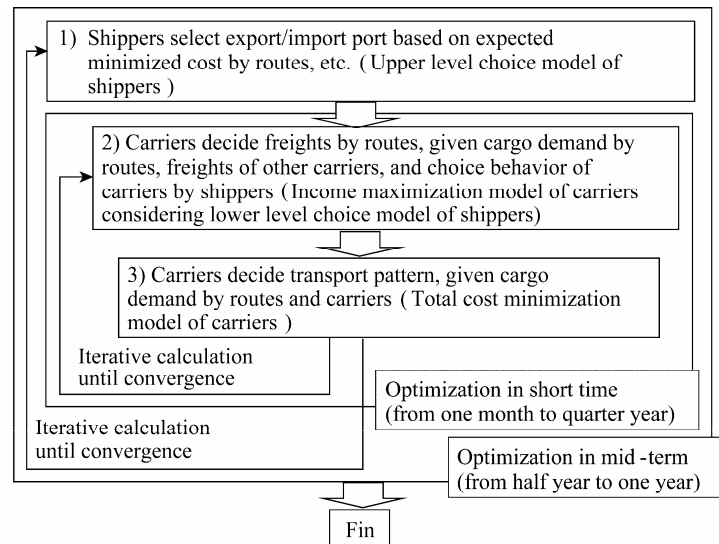


Fig.4 Flowchart of the entire model calculation

3.2.2 Data preparation

The inputted data required for the model can be divided into four types; 1) amount of OD container cargo by region; 2) transport network data such as physical distance and operational costs including both international maritime shipping and hinterland transport; 3) service level of each port, such as the number of berths by depth, various fare and costs associated with berthing and sizes; 4) initial input such as link flow between ports by ship size and by carrier and total volume of containers handled at port. This model was basically developed based on 2003 data, where the latest data are available such as survey report of international container cargo flow, conducted by Japanese government every five years. These four types of data are all difficult to be obtained, especially the amount of container OD data.

The first model was developed under a network including 17 Japanese container ports, 8 Chinese ports, and 25 other Asian ports. The number of categories in containership size was four (under 1 000 TEU, 1 000~2 500 TEU, 2 500~4000 TEU, over 4 000 TEU). In addition, Japanese land transport network was only included as hinterland transport network; therefore, import/export port choice behavior of shippers was only considered for Japanese cargo.

3.2.3 Model solution and accuracy

Out of many exogenous variables in the formulations of the model, variance parameter on Gumbel distribution included in a logic model, θ , and money-cost conversion factor (value of time for carriers) in the carrier sub-model, V_{carr} are the most difficult to be exogenously given for optimal values among others, because data accumulation on the actual values of them are inadequate at all. Therefore, the optimal values of these parameters are decided to reproduce the actual container cargo flow pattern in the model, by applying a steepest descent method, which is one of the optimization methodologies.

The reproducibility of the container cargo throughput for export/import is shown in Fig.5(a). Here, since shippers' port choice behavior is only considered for Japanese cargo in the first model, the comparison of the actual and estimated volume is shown only for Japanese ports. As shown in the figure, container cargo throughput for export/import was reproduced well by the developed model in most of Japanese ports. Fig.5(b) shows the reproducibility of the volume of transshipped container cargo in all Asian ports. As shown in the figure, they were also reproduced well in most of Asian ports.

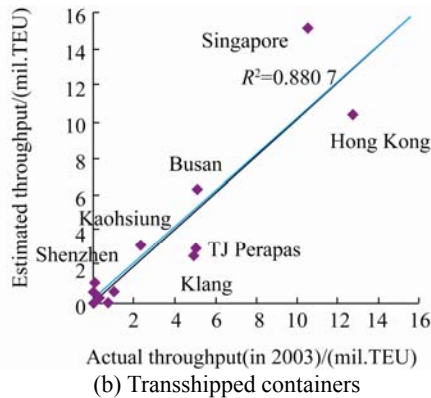
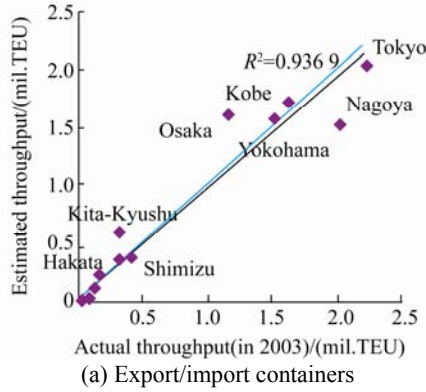


Fig.5 Reproducibility of export/import and transshipped container cargo throughput for Asian ports (in 2003)

3.3 Model extension

In order to give simulations in the PRD, Chinese land transport network needs to be incorporated in the above-developed model. The research attention was focused on the evaluation of the entire Chinese infrastructure investment; therefore, the hinterland network was very rough. In this paper, detailed land transport network is incorporated in Guangdong province, and OD zones in the region are also finely divided. In Guangdong province, totally more than 27 000 km network with 7 695 links, derived from ADC World Map. Also, the OD zones are divided into county or town level cities in the PRD, and divided into prefecture level cities for other cities in the province to be 109 zones in total. In order to estimate prefecture and county level data from the province level data, the cargo demand is divided in proportion to the share of trade amount by partner countries in each city, which are available from China Trade Information data. On the other hand, into the town level are they divided according to the regional output of manufacturing derived from Guangdong Statistical Yearbook.

The reproducibility of the extended model is shown in Fig.6. In the figure, the comparison between the actual and estimated total (i.e. export/import and transshipped) container cargo throughputs by terminals in the PRD is shown. According to the figure, the estimated throughput by

the extended model seems to reproduce the actual well.

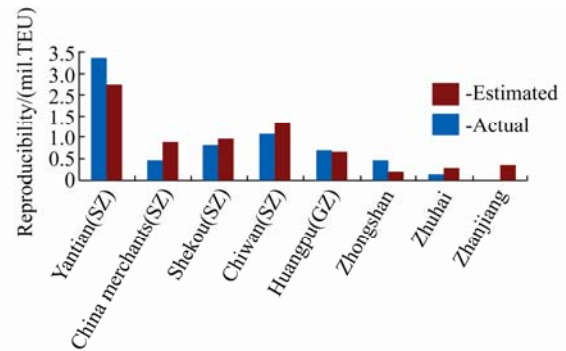


Fig.6 Reproducibility of total container cargo throughputs for ports/terminals in Guangdong province (in 2003)

4 Simulation for container terminal and related infrastructure construction

Using the model described in 3.1, future container cargo flows are simulated with the following scenarios on future OD container cargo and infrastructure investment as input.

Scenario 1: 2007 OD cargo and infrastructure. The simulation model introduced in the previous chapter was developed with year 2003 data and the actual cargo flow was reproduced at that year. In this scenario, OD container cargo matrix, an input data of the model, was updated to the year 2007 data. In addition, two terminals (i.e. DCB-CT and Guangzhou Nansha terminal) and several expressways including Hong Kong-Shenzhen Western Corridor (see section 2.2) in the PRD area that had opened during 2003~2007 are added into the model network.

Scenario 2: 2015 OD cargo and infrastructure. In addition to Scenario 1, OD cargo is further increased with increasing ratio of that for the past five years. Also, further infrastructure investments are made in each terminal (including DCB-CT, other terminals in the PRD, and other terminals in the world) as well as new expressway along the coast around DCB-CT. Furthermore, this scenario is divided into two sub-scenarios; Scenario 2A: equal competition among terminals, and Scenario 2B: incentive to use DCB-CT by discounting port and handling charges (-30%) and shortening lead-time (-25%), compared with other terminals.

Scenario 3: 2020 OD cargo and infrastructure. In addition to Scenario 2, OD cargo is further increasing again. Besides, further infrastructure investments are made in each terminal as well as the opening of Shenzhen-Zhongshan bridge connecting the nearest point of DCB-CT and urban district of Zhongshan across the Pearl River estuary. Also, two scenarios are prepared; Scenario 3A: equal competition among terminals, and Scenario 3B: incentive to use DCB-CT.

The simulation results are summarized in Table 1 and Fig.6. As shown in Table 1 and Fig.6, in 2007 (Scenario 1), the opening year of DCB-CT, the estimated cargo throughput in DCB-CT is quite a few (share of export/import cargo is only 1.4% as shown in Fig.7), contrastingly that another new terminal, Nansha Terminal, shares a large proportion (19% as well). In 2015 (Scenario 2), the share of DCB-CT is very different between Scenario 2A (4.5%) and 2B (17%). This means the incentive is very important and critical to the terminal. By discounting charges and shortening lead-time, cargo exported from/imported into other Shenzhen terminals and Nansha terminal will easily shift to DCB-CT. In contrast, in 2020, the share of DCB-CT is quite large no matter the incentives exists (Scenario 3B, 19%) or not (Scenario 3A, 17%). This is mainly because in the 2020 network,

Shenzhen-Zhongshan Bridge is assumed to open. For Scenario 3A, after its opening, most cargo originated from/destined into the west PRD area will be transported by trucks to terminals in the east coast terminal of the PRD; in particular, it affects DCB-CT most due to its closet location to the bridge. Of course, the bridge is just under the planning stage as well as other bridges crossing the Pearl River estuary such as Hong Kong-Zhuhai-Macau Bridge, and simulation results depends on what land transport network is assumed. However, through the above simulations it can be concluded that the improvement of the land transport network is very important for estimating the cargo throughput of container terminals as well as investment to port itself.

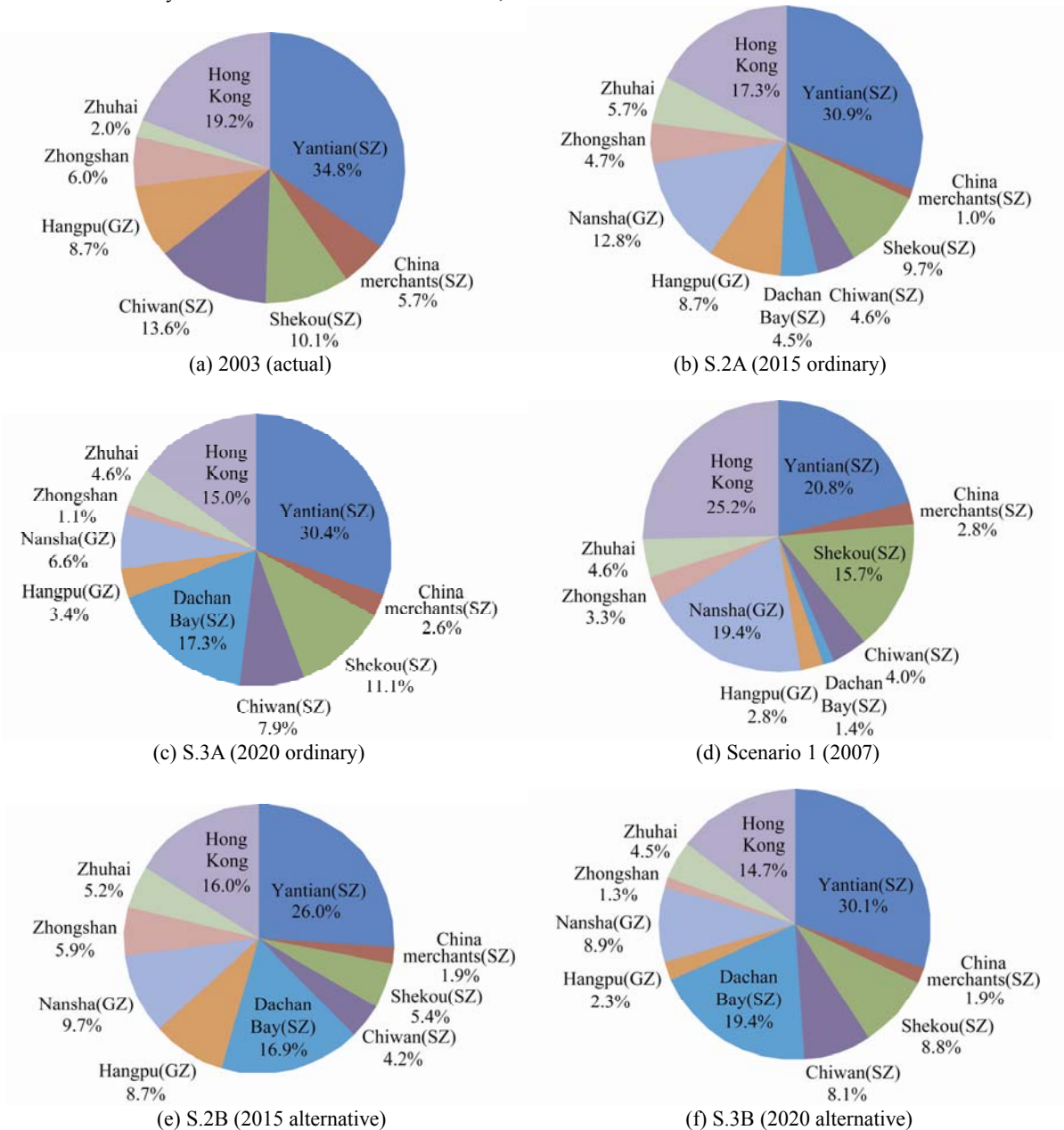


Fig.7 Share of export and import cargo in the PRD CTs by scenarios

Table 1 Container cargo throughput (in total) of the PRD terminals estimated by simulation

Total cargo	2003		Scenario 1	Scenario 2 (2015)		Scenario 3 (2020)	
	actual	estimated	(2007)	2A	2B	2A	2B
Yantian (SZ)	3.33	2.61	5.93	18.64	17.34	20.57	23.58
China Merchants (SZ)	0.54	1.03	0.47	0.00	0.91	1.78	1.16
Shekou (SZ)	0.97	1.17	4.78	8.86	8.83	21.33	23.61
Chiwan (SZ)	1.30	1.60	1.53	2.71	2.77	11.81	12.62
Dachan Bay(SZ)	0.00	0.00	0.55	2.08	10.34	11.01	15.54
Huangpu (GZ)	0.83	0.79	0.43	3.55	3.54	2.58	1.60
Nansha (GZ)	0.00	0.00	3.41	6.60	5.04	4.34	5.47
Zhongshan	0.57	0.28	0.53	1.76	2.25	0.60	0.70
Zhuhai	0.20	0.34	0.69	2.27	1.99	3.15	2.61
HK	14.74	7.65	18.32	48.86	55.18	60.78	69.74
PRD							
Total33	22.48	15.47	36.09	95.71	108.19	137.94	156.63

5 Conclusion

In this paper, the authors summarized the competitive situation among container terminals in the Pearl River Delta, especially focusing on new terminal, Da Chan Bay CT. In addition, by applying the developed model after some modification and extension, future container cargo throughput by terminals and flow on the land transport network were simulated. Although the original model was developed in order to simulate container flow at the world-wide level rather than the local level, the results acquired in this paper's simulation is also considered to be reasonable. In particular, it is a great harvest of this paper that growth of a new terminal can be sequentially simulated. Furthermore, it can also prove the improvement of the land transport network is very critical to the terminal as well as investment to port itself.

The authors will continue to improve the accuracy of the model introduced in this paper and extend to simulate other regions as well, and in the meantime, try to develop and improve the methodologies on how to estimate future OD

cargo demand, which is a prerequisite of this kind of simulation.

References

- China Ports Yearbook Editorial Board (annually). China Ports Year Book. China Port Press, Shanghai.
- Dial R (1971). A probabilistic multipath traffic assignment algorithm which obviates path enumeration. *Transport Research*, 5(2), 83-111.
- Ieda H, Shibasaki R, Naito S, Mishima D (2000). Model development for East Asian container shipping considering multifarious use of vessels and ports. *World Conference on Transportation Research Proceedings*, 8(3), 213-226.
- National Bureau of Statistics (annually). China Statistical Yearbook. China Statistical Press, Beijing.
- Shibasaki R, Ieda H, Watanabe T (2005). An international container shipping model in East Asia and its transferability. *Research in Transportation Economics*, 13, 299-336.
- Shibasaki R, Kannami Y, Onodera H, Li J, Miao L (2007). Impact of Chinese port policy using the model for international container cargo simulation. *Journal of the Eastern Asia Society for Transportation Studies*, 7, 1083-1098.
- Sheffi Y (1985). *Urban transportation networks*, Prentice-Hall, Englewood Cliffs, New Jersey.



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