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Modelling International Maritime Container Cargo Flow and Policy Simulation in South Asia: An Application of Network Equilibrium Assignment Model on a Global Scale

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Abstract

This paper develops a model to predict worldwide container movements on the international maritime shipping network, by applying a network equilibrium assignment methodology, based on data as of 2013. Every international maritime container in the world which is transported by major shipping companies is assigned on the maritime shipping network, under the given shipping demand between seaports. Since it is a simple application of the network equilibrium assignment model, all seaports of the world which handled more than 500 thousand TEU in 2013, as well as local ports in South Asia and neighbouring regions that this paper focuses on, can be included in the model.
After the convergence check of the model calculation, the model outputs are examined mainly from the viewpoint of the containers transhipped at each port. As a result, the model well describes the actual transhipment rate and volume in major hub ports of the world. Additionally, the container flows transhipped at Colombo Port, which is the only major hub port in South Asia, are summarized by the shipping company and region in which each service is in operation. Finally, two kinds of policy simulation, namely, a decrease of transhipment time and the construction of new transhipment hub in South Asia, are examined by applying the developed model.

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Keywords: International container cargo; Maritime policy; South Asia; Network equilibrium assignment model; global maritime shipping network

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1. Introduction

Due to globalization of the world economy, the importance of international maritime container shipping has been increasing year by year. Furthermore, economic globalization is strengthening the relationships among containership movements in each region of the world. Liner shipping companies are expanding and strengthening their shipping network on a global (i.e. worldwide) scale, not only by deploying larger containerships, but also through mergers and alliances. Connectivity with hinterlands (i.e. land shipping network) and competition among multiple seaports as gateways have also become focal points in international container shipping.

South Asian countries, including India, Sri Lanka, Pakistan and Bangladesh, are falling behind the global trend of the maritime shipping market. According to the World Bank Group’s rankings of business environment in terms of international trade, these South Asian countries placed 69th (Sri Lanka) at best, followed by 108th (Pakistan), 126th (India) and 140th (Bangladesh).

The total throughput of international maritime containers which are exported from or imported into South Asia is also relatively less compared with other regions of the world. For example, the total container throughput in India was 10.7 mil. TEU (twenty foot equivalent unit) in 2013, while throughput in China was 174.1 mil. TEU (World Bank, 2015), despite the fact that the populations of both countries are at a similar level. In addition, the transhipment rate in the region is low. Fig. 1 shows the rate of transhipped containers (the number of total transhipped containers divided by the total container throughputs for each region) by region for regions located along the trunk line connecting Europe and East Asia. Compared with other regions, including Europe and Northeast Asia, the transhipment rate in South Asia is rather low, especially after 2010. The significant increase in South Asia which is observed in the 1980s in Fig. 1 was caused by the development of Colombo Port (Sri Lanka), which is still a unique, major hub port in the region. Although the transhipment rates in other regions have increased in recent years, the rate in South Asia has seemingly reached a plateau since the 1990s.

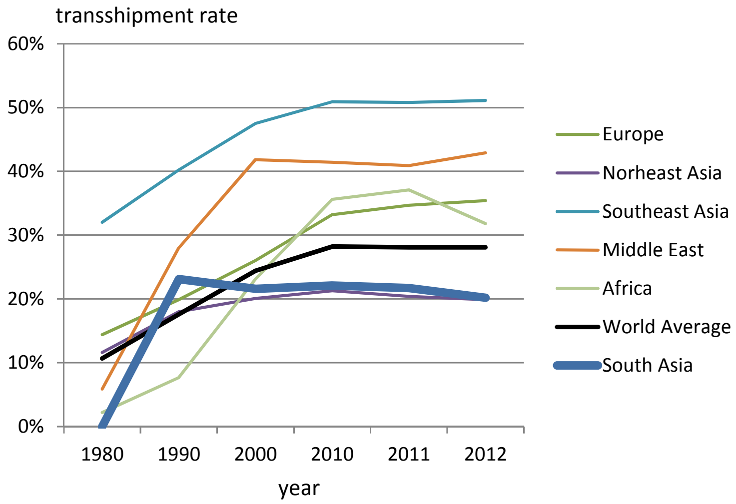


Fig. 1. Transhipment rate by region along the trunk line between Europe and East Asia. “World Average” also includes other regions (e.g. North America and Latin America) from those shown in the figure. Source: the authors, based on Drewry Maritime Research, 2014a.

A model has been developed to predict worldwide container movements on the international maritime shipping network by applying a network equilibrium assignment methodology (the authors, 2013). The model was developed from the viewpoint of cargo owners (shippers) under the condition that the level of service in each liner shipping (as provided by each shipping company) and in each port (provided by each terminal operator) are given as exogenous variables. Many papers introduce models to acquire the optimal shipping network and/or the level of service in each liner shipping from the viewpoint of shipping companies (carriers) (e.g., Meng et al., 2014; Wang et al., 2013;

Christiansen et al., 2013), but papers which focus on the shippers' viewpoint are quite limited. Such examples include Bell et al. (2011) and Tavasszy et al. (2011). The former applies a frequency-based traffic assignment model to the maritime container assignment problem on a given liner shipping network with frequency and other strategic variables. The latter assigns world container cargo into an intermodal network including land and maritime shipping by a path size logit model, but does not consider any actual liner shipping service.

The model presented in this study applies a network equilibrium assignment model to the international maritime shipping network on a global scale. In this model, every international maritime container in the world which will be transported by major shipping companies is assigned on the maritime shipping network where any liner service of the major shipping companies is provided, and the shipping demand between seaports are given. The model's output is container flow by each liner service, which implicitly includes the choice of shipping companies by shippers. Additionally, the model predicts in which port each container is transhipped if needed; in other words, the transhipment volume in each port can be estimated by the model. Since the model is a simple application of the network equilibrium assignment model, it can include the more than 170 seaports in the world which handle more than 500 thousand TEU a year. In this paper, the model is developed on data as of 2013, particularly focusing on South Asia, by including many minor ports in South Asia and neighbouring regions (e.g. the Indian Ocean, the Middle East and East Africa). Also, details on the estimated cargo flow in South Asia are examined with particular focus on the containers transhipped at Colombo Port, the sole major hub port in South Asia. Future scenarios on a decrease of transhipment time and the development of new container hub in South India are also applied to the model.

2. Model

The model is defined as a problem to allocate container cargo on the worldwide liner shipping network with a capacity constraint of vessel, where every liner service in the world is described as an individual link, as shown in Fig. 2. The real network is structured from the MDS Containership Databank. A route is chosen for each container to minimize total transit time from the origin port to the destination port. In this simplified model, the shipper is assumed to choose a carrier based only on shipping time with no consideration given to the freight charge. This assumption is based on the understanding of the international maritime container shipping market, which is oligopolistic but very competitive in terms of price; in other words, it is assumed that the freight charge for an OD pair is the same among carriers if the service is provided and utilized. Severe competition among shipping companies surely exists in the real shipping market; however, some may consider the assumption of equal freight is an oversimplification. Results from interview surveys with shipping companies indicate that it may be more realistic to assume that each shipping company competes on a generalized cost, including both shipping time and freight charge. A more complex model to describe competition in terms of generalized cost based on contestable market theory is being considered as a next step.

Since vessels of each service have their own capacities, there is a diseconomy of scale by concentrating the cargo into a specific service. Therefore, the congestion of the link is considered and a User Equilibrium (UE) assignment is applied as the network assignment methodology based on Wardrop's first principle (1952).

$$\min_x z(x) = \sum_{a \in A} \int_0^{x_a} t_a(x_a)dx \tag{1}$$

s.t. $$x_a = \sum_{(r,s) \in O \times D} \sum_{k \in K_{rs}} \delta_{a,k}^{rs} \cdot f_k^{rs}, \ \forall a \tag{2}$$

$$\sum_{k \in K_{rs}} f_k^{rs} - q_{rs} = 0, \ \forall r,s \text{ , and} \tag{3}$$

$$f_k^{rs} \geq 0, \ \forall k,r,s, \tag{4}$$

where a: link, A: set of link, x_a: flow of the link a, t_a: cost function of the link a, z: objective function, r: origin, s: destination, O: set of origin, D: set of destination, k: path, K_{rs}: set of path for OD pair rs, δ_{krs}: Kronecker delta, f_{krs}: flow on the path k, and q_{rs}: cargo shipping demand from r to s. Kronecker delta, δ_{krs}, is written as

$$\delta_{a,k}^{rs} = 1 \text{ if } a \in k; = 0 \text{ if } a \notin k. \tag{5}$$

The definition of each cost function is described below.

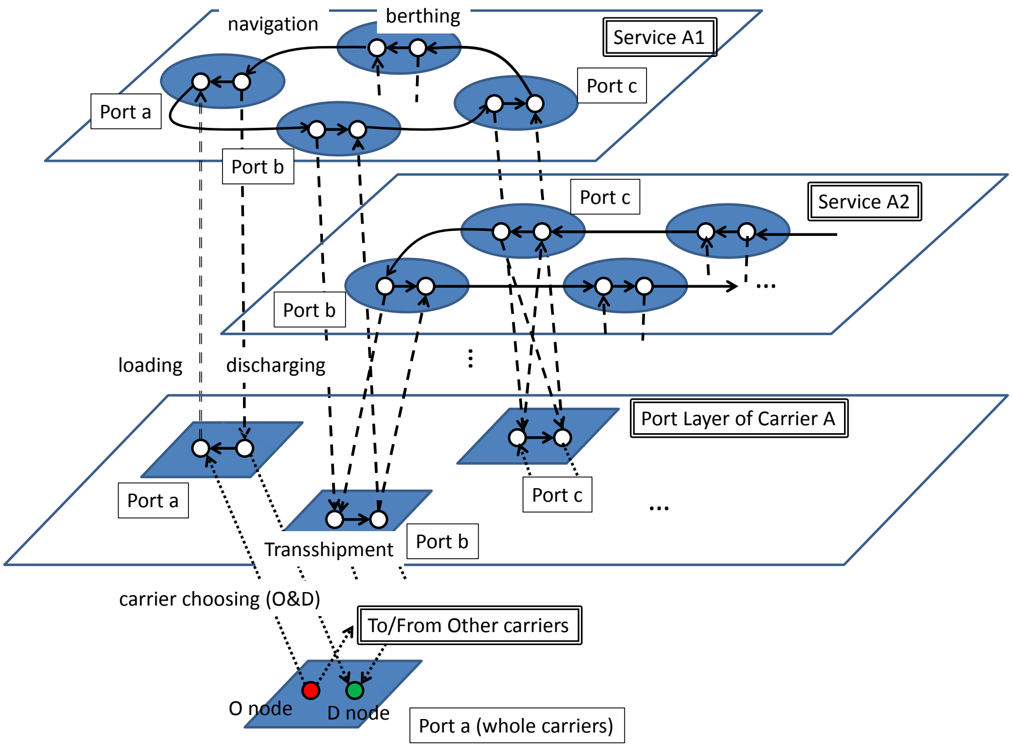


Fig. 2. Network structure of the model

2.1. Navigation link

A navigation link connects each port by each liner service on the sea. The link cost includes shipping time and congestion due to the capacity constraint of vessel.

$$t_n(x_a) = \left(\frac{l_a}{v_a} + \gamma_a^s \cdot TS + \gamma_a^p \cdot TP \right) + TW_{a'} \cdot b1 \left(\frac{x_a}{cap_a \cdot freq_a} \right)^{b2}, \tag{6}$$

where t_n: shipping time of the navigation link (hour), x_a: container cargo flow of the link a (TEU/year), l_a: distance of the link a (nautical mile), v_a: vessel speed of the link a (knot), γ_a^s: dummy variable on the Suez Canal transit (=1: if link a passes through the Suez Canal; =0: in other cases), TS: additional time for Suez Canal transit (set to be 24 hours), γ_a^p: dummy variable for Panama Canal transit (=1: if link a passes through the Panama Canal; =0: in other cases), TP: additional time for Panama Canal transit (also set to be 24 hours), a': loading link in the departure port of the navigation link a, $TW_{a'}$: expected waiting time for the loading of the loading link a' (hour), cap_a: average vessel capacity of the service (TEU/vessel), $freq_a$: service frequency (vessels/year), and $b1$, $b2$: parameters related to the congestion. The first term of the equation is the shipping time without any congestion, including the transit time of the Suez Canal and Panama Canal. The second term represents the delayed time due to the congestion.

The delayed time is defined by multiplying the waiting time for the loading as shown in Equation (6) by the congestion function, which may have some relationship with a load factor ($x_a/cap_a/freq_a$).

$$TW_{a'} = \frac{1}{2} \cdot \frac{YH}{freq_a}, \tag{7}$$

where YH: constant for conversion from one year to hours (52 (weeks/year) ·7(days/week) ·24(hours/day) = 8,736 (hours/year)). The term ($YH/freq_a$) represents duration hours of each vessel of the service. The expected waiting time is assumed to be half of that value.

Several definitions for the congestion term can be considered in the model. Among them, two major issues are in which link the congestion cost should be imposed and which cost should be multiplied. On the first point, the congestion cost should be seemingly imposed with a cargo flow of the loading cost (see 2.2), since the delay of cargo is normally observed in the port as left-behind. However, in the assignment model, the congestion cost tends to be imposed in the cargo loaded from the ports with the subsequent order for call as a vessel approaches the last port. It is not fair, and in reality the shipping company controls a load factor from the first port when the cargo is expected left-behind. Therefore, it is better that the congestion cost is imposed with the cargo flow of the navigation link to reach an equilibrium easier. The second point on the definition on the congestion term is whether it should be related with the navigation time (l_a/v_a) or expected waiting time for the loading (TW_a), in case that the congestion term is included in the navigation link. Since the delay of cargo is normally observed in the port as left-behind as stated above, this model assumes that the congestion term should be related with the expected waiting time for the loading.

2.2. Loading link

A loading link connects from a port layer to each liner service in each port by each shipping company. The link cost t_l (hour) of a loading link a is defined as the sum of the loading time and the expected waiting time for departure, related with the frequency of each service.

$$t_l(x_a) = TL_a + TW_a, \tag{8}$$

where t_l: time of the loading link (hour), and TL_a: loading time of the loading link a (hour).

2.3. Discharging, berthing and transhipment link

A discharging link connects from each liner service to a port layer in each port by each shipping company, inversely with the loading link. An anchoring link represents each liner service in the port for a container which is on board a vessel (i.e. neither discharged nor loaded). A transhipment link will be passed if a container is transhipped from one service to another.

It is assumed that transhipment is only allowed within the same shipping company. This is a rather strong assumption, since in reality, major shipping companies often utilize feeder services provided by local shipping companies; however, it is more realistic if compared with the case assuming that any transhipment among different shipping companies is allowed without any restriction. Pursuit of the golden mean for both assumptions (i.e. in some conditions it is allowed but in other conditions it is not allowed) is difficult, since an automatic criterion for judgment has to be established.

The link cost of these links are defined as

$$t_d(x_a) = TD_a, \tag{9}$$

$$t_b(x_a) = TB_a, \text{and} \tag{10}$$

$$t_r\left(x_a\right) = TR_a\ , \tag{11}$$

where t_d: time of the discharging link (hour), t_b: time of the berthing link (hour), t_r: time of the transhipment link (hour), TD_a: discharging time of the discharging link a (hour), TB_a: berthing time of the berthing link a (hour), and TR_a: transhipment time of the transhipment link a (hour).

2.4. Carrier choosing link

In this model, container shipping utilizing multiple carriers is not allowed. (In other words, each container should be transported by only one carrier.) Therefore, the cost of the carrier choosing link, t_c (hour), has to be set at a sufficiently small number to avoid transhipment of the container between carriers.

$$t_c\left(x_a\right) = SSN\ , \tag{12}$$

where t_c: time of the carrier choosing link (hour), *SSN*: sufficient small number (actually, set to be 0.01 (hour)).

2.5. Solution

Of the networks which are introduced above, only the navigating link has a flow-dependent cost function. The cost functions of other links are flow-independent. Therefore, the UE problem defined in Equation (1) will be solved in the algorithm shown by Sheffi (1985).

3. Data

3.1. Ports

The world liner shipping network formed by the major shipping companies is covered under this model. In principle, all container ports at which throughput was more than 500,000 TEU per year as of 2013 (including empty containers) are included. The estimated quantities of transhipped containers in world's major hub ports (which handle more than 1 mil. TEU transhipped containers per year) are available from Drewry Maritime Research (2014a). However, acquiring the list of the world container ports which handles more than 500,000 TEU in total per year has become difficult, since such data sources (such as CI-online or Containerisation International Yearbook) are no longer available. As a result, the port list for this study was made mainly from the following sources:

a: Drewry Maritime Research (2014a) - Appendix 3: Port throughput quarterly comparison;
b: Lloyd's List: Top 100 Container Ports 2013;
c: China Port Yearbook Publishers (2014) (only for ports in Mainland China);
d: Drewry Maritime Research (2014b) – Estimated throughput is available for each container terminal where worlds' major terminal operators are in operation;
e: Websites for each port or terminal; and
f: Substitution with a past record (e.g. as of 2012, 2011) (in case that data is not available from any of the sources listed above).

From the sources listed above, the total number of ports considered in the model as of 2013 is 173. The complete port list is shown in Appendix A1. Note that some ports that are closely located to each other, such as Singapore and Jurong, and Puerto Manzanillo and Cristobal in Panama, are treated as one port. On the other hand, Shenzhen Port (China) is divided into i) Yantian terminal and ii) Shekou and other terminals, due to the fact that they are located on opposite sides of Hong Kong Port.

Another topic is the treatment of domestic containers. Since the container throughput of each port is utilized in estimating the international cargo shipping demand between ports as described in 3.3, domestic containers should be subtracted from the total throughput. However, statistics on domestic containers is generally difficult to acquire. The exception is for Chinese ports, where the number of domestic containers (including feeder containers of international shipping) handled is available from China Port Yearbook Publishers (2014), and in some ports constitutes a large share of throughput. As a consequence, twelve Chinese ports (such as Yingkou, Rizhao and Quanzhou) which handle less than 500,000 TEU for international containers are not included in the list.

In addition, the port list shown in Appendix A1 also includes 21 local container ports in South Asia and neighbouring regions (coloured orange); therefore, the total number of container ports considered in the model is 194. All local ports that include at least one international liner service call in South Asian countries are considered. Also, some local ports in Southeast Asia (Myanmar), Middle East (Oman), East Africa (Mozambique and Tanzania), and Indian Ocean Islands (Seychelles, Comoros, Madagascar, Reunion, and Mauritius) are included. The container throughput for each port is acquired from various sources, including websites of port associations, international organizations such as the World Bank and the United Nations World Food Programme, and interviews with port trusts and other organizations for this study.

The table in Appendix A1 also shows a transhipment time, TR_a, which is included in Equation (11), estimated by the authors judging from the comprehensive level of service in each port. Since TR_a includes loading and unloading times, TL_a and TD_a in Equations (8) and (9) for every port are set equal to *SSN* (i.e. 0.01 hour). Also, a berthing time, TB_a, in Equation (10), is constantly assumed to be 12 (hours) for every port of every liner service.

3.2. Maritime shipping network

The Maritime shipping network was developed using the MDS containership databank. The MDS database provides information for each containership such as vessel name, IMO number, name of service, operator name (carrier), partner company(ies) of the service (if any), slot chartered company(ies) (if any), route category defined by MDS, list of port to call and its order, service frequency (yearly basis), TEU Capacity, DWT, vessel speed, etc. After aggregating this vessel-basis data (5492 vessels as of June 2013) into service-basis (2569 services), the maritime shipping network was structured. From the database, the ports which are not included in the model are eliminated. Also, vessel speed, v_a (knot), average vessel capacity, cap_a (TEU/vessel), and frequency, $freq_a$ (vessels/year) in Equations (6) and (7) can be acquired for each service from the MDS database.

When a service is operated by multiple companies, the assumption is that the vessel capacity is divided equally by the number of operators. When a service has a slot charted company(ies), the vessel capacity for the slot charted company(ies) is assigned to be half of the capacity of each operator (by assumption). For simplicity of model calculation, congestion due to capacity constraint in the model is calculated by each company, even in the same vessel; namely, a capacity assigned to each company as above is not allowed to accommodate between companies, even if a space for one company is very crowded but that for another company is less crowded.

Since the model focuses on the container flow on the worldwide maritime shipping network and the transhipment of containers in hub ports, some liner services provided by smaller, local companies less involved with South Asia are eliminated for simplicity of calculation. Specifically, the model includes the 20 largest container shipping companies in the world as well as fourteen local companies which have a liner service network in South Asia. The list of shipping companies is shown in Appendix A2. 932 services are included in the model, covering 68.9% of the annual vessel capacity of the world.

Several ports, i.e.,Weihai (China), Suzhou (China), Nanjing (China), Wuhan (China), Zhongshan (China), Zhuhai (China), Makassar (Indonesia), Mumbai (India), Honolulu (USA) and Duisburg (Germany), are not included in the MDS database or are not sufficiently covered (less than 30% of the total capacity) by the above companies considered in the model, therefore they are eliminated from the port list described in 3.1 and not included in Appendix A1.

The distance between ports, l_a (nautical mile), is acquired from Toriumi's work (2010) as in the previous model. The distance is calculated from an assumption that every container ship passes through the shortest route on the sea out of the pre-set navigation routes. The dummy variables for Suez and Panama Canal transit, γ_a^s and γ_d^p, are also acquired from it. Some distances to/from several local ports which are newly added to the model as of 2013 (see 3.1) are acquired from several websites such as SeaRates.com and Sea-Distances.org

3.3. Container shipping demand (OD matrix)

The demand of container cargo shipping, q_{rs}, from port r to s is estimated as follows. First, the demand of container cargo shipping (OD matrix) between countries or regions on a TEU-basis is obtained from the World Trade Service (WTS) database provided by IHS, Inc. The current version of the WTS data provides a container shipping demand for each year (from 2000 to 2030) among 117 countries/regions of the world (except for “others”, in which certain countries/regions are not clear). However, some countries/regions in the WTS data are landlocked or do not have any seaports which handle more than 500,000 TEU a year. Also, hinterland transport across national borders can be observed in some regions, such as in Europe and North America. Therefore, the OD matrix is aggregated into 46 countries/regions as shown in Appendix A3, considering the characteristics of hinterland transport. Appendix A3 also shows a comparison of the volume of shipping demand in each aggregated region, with the container throughput aggregated into the same regions (which is obtained by eliminating the transhipment containers and empty containers from the port throughput shown in Appendix A1 before the aggregation; note that the rate of empty containers is assumed to be constantly 24.0% throughout the world, according to Drewry Maritime Research, 2014a). As shown in the table, both the shipping demand and container throughput are similarly equal in some regions, but they are very different in other regions. For example, the shipping demand is much larger than the throughput in “Central Africa”, “West Africa” and “North America Atlantic Coast & Carib”. This may be because statistics on the cargo throughput in these regions are not sufficient. On the other hand, the throughput is larger than the shipping demand in “China”, “India”, “Indian Subcontinent Islands”, “Philippines” and “Southern African Islands”. Several reasons are considered, such as an overestimation of the throughput (China), an underestimation of the empty containers due to significant imbalance between export and import trade than the world average (China and India), and an inclusion of domestic or inter-islands containers (India, Indian Subcontinent Islands, Philippines and Southern African Islands). In particular, the overestimation (or over-reporting) of the container throughput in China is said to distort the understanding of the world’s maritime container shipping and its elimination would be significant (see for example, Drewry Maritime Research, 2013). The authors estimate that it is one of significant reasons why the total throughput of the world (269 mil. TEU for the sum of export and import) is quite larger than the total shipping demand (238 mil. TEU) as shown at the bottom of Appendix A3 (other possible reasons of the difference in the total amount are that intra-European cargo is not included in the WTS data, and that the cargo to/from “other” region is not included in the table).

The second step for estimating demand for container cargo shipping is dividing the aggregated OD matrix above into a port-basis according to the port’s share of the export and import container cargo throughput of the aggregated region. Then, the third step is to eliminate the containers that will be shipped by the companies which are not included in the model. This is necessary for the balanced calculation of the model between the vessel capacity and the amount of containers shipped in each service. This is obtained by first subtracting the total amount of shipping demand by the share of carriers which are not considered in the model for each port based on the share in vessel capacity arriving at and departing from each port. Then, the Frater method is applied to adjust errors by inputting the total amount of shipping demand for each port for the target carriers as given and the OD matrix estimated in the previous section as initial inputs.

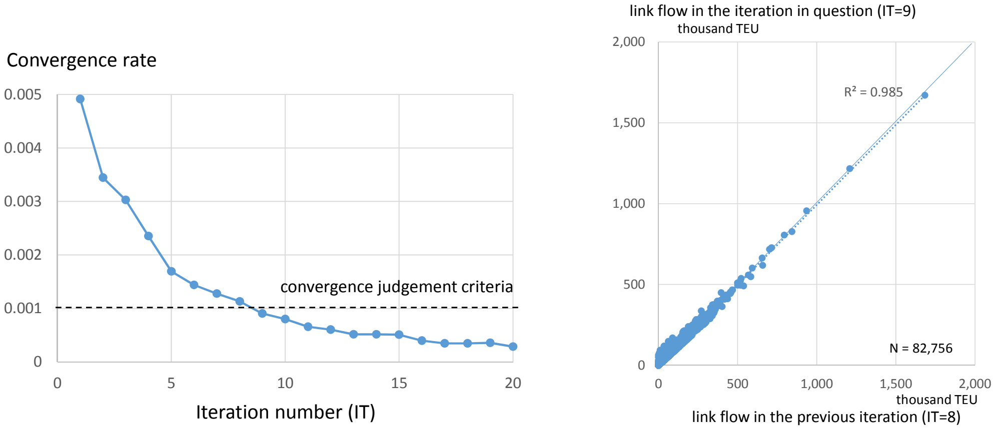
4. Model Output

4.1. Calculation and convergence

The two parameters related to the congestion included in Equation (6) are set ($b1$, $b2$) = (2.308, 1.017) as per the authors’ previous study (2013). These values imply that when the load factor is 100% (i.e., $x_a/(cap_a \cdot freq_a) = 1$), the equivalent additional time due to congestion is slightly more than the duration time of the service ($YH/freq_a$). This is a reasonable setting, since the congestion is normally observed in the port as left-behind, as previously stated.

The number of links in the network is 82,280. The calculation time for one iteration of the Frank-Wolfe algorithm is three to five minutes by using a laptop Windows computer with an Intel® Core™ i7 vPro-5600U™ Processor and 8.00 GB of RAM. The convergence rates of each iterative calculation (the sum of squares of the differences of the link flow calculated in the iteration from that in the previous iteration) are shown in Fig. 3(a). The comparison between the calculated link flow and the link flow in the previous iteration when the convergence rate first becomes less than

10^{-3} is shown in Fig. 3(b). Considering these results and the calculation time, 10^{-3} is sufficient as a criterion of judgement of convergence.



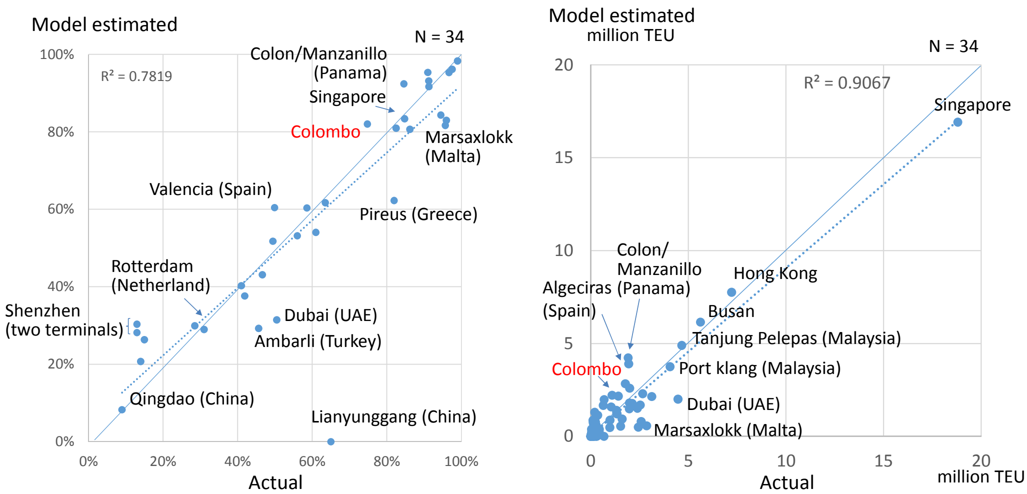
(a) Convergence rate of each iteration (b) Link flow change around convergence judgment criteria

Fig. 3. Convergence of the model

4.2. Transhipment containers

One of the greatest features of the model is to describe transhipment at each port. The comparison for major hub ports (which handle more than 1 million TEU transhipment containers) in terms of transhipment rate and volume between the actual and model estimated cases are shown in Fig. 4. The total throughput of transhipped containers estimated for all ports included in the model is 106.09 million TEU, while the actual amount is 106.06 million TEU. Judging from these observations, the developed model can predict the transhipment containers handled at each hub port rather well.

The largest difference in terms of transhipment rate in Fig. 4 is observed in Lianyunggang Port (China), where the estimated transhipment rate is zero. The reason for the underestimation is that most of the domestic feeder services from/to Lianyunggang Port are supplied by other small carriers which are not considered in the model.



(a) Transhipment rate (b) Transhipment throughput

Fig. 4. Comparison in terms of transhipped containers between the actual and model estimated cases at major hub ports

In order to check the container flow for the hub port in South Asia, Colombo Port, the network structure shown in Fig. 2 is changed only at Colombo Port. At Colombo Port, a transhipment link is structured for every combination of two liner services in the same company which call at Colombo Port. By introducing such multiple transhipment links, which service (or which combination of services) containers aboard is more likely transhipped in the port can be observed. Note that the transhipment link is separately structured if a service calls at Colombo Port twice (i.e. eastbound and westbound) in one loop. In the following analysis, multiple transhipment links are structured only at Colombo Port in order to reduce the number of added links (in total, 476 links are added).

The number of containers transhipped at Colombo Port is estimated at 1,076,974 TEU by the model (note that the number of containers is normally doubled for calculating the transhipment throughput as shown in Fig. 4(b)). Fig. 5 shows a breakdown by shipping company. Maersk, the largest container shipping company in the world, and its affiliated companies (Group A) share the largest portion, followed by Evergreen (Group D) and CMA-CGM (Group C). X-Press Feeders (Group U), a regional shipping company, also shares a significant portion.

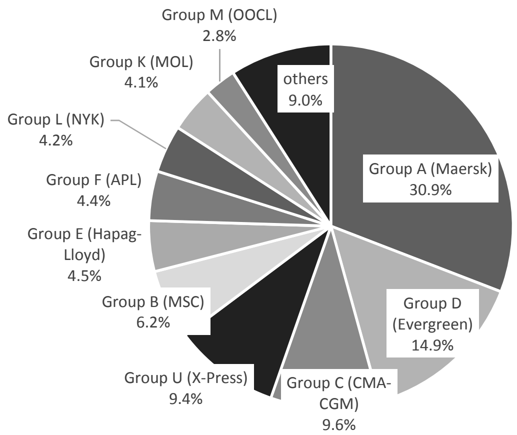


Fig. 5. Estimated share of each shipping company in the containers transhipped at Colombo Port (source: the authors)

Of each combination of two liner services, the largest amount (55,164 TEU) is also Maersk's containers transhipped from the UBB service operated by X-Press Feeders (Maersk partly charters its slot) connecting with Chittagong (Bangladesh) to the AE7 service connecting with North Europe, followed by CMA-CGM's slot charter connection (26,368 TEU) from the UBB service to the CES service operated by Evergreen to North Europe.

Table 1 summarizes the container flows transhipped at Colombo Port which are estimated in the model. Geographical locations for each region categorized in Table 1 are shown in Fig. 6. The largest amount of transhipped containers is observed from the Bay of Bengal and Indian East Coast (BB-IE) to the Mediterranean, Europe, and East Coast of North America (MEE) (178,839 TEU) which includes both combinations of services (i.e. Maersk and CMA-CGM) described above. Other major transhipment patterns are from the Arabian Sea and Indian West Coast (AS-IW) to MEE (121,022 TEU) and from MEE to BB-IE (108,969 TEU), which is opposite the largest route.

Through additional summarization, containers transhipped from neighbouring regions (i.e. the Bay of Bengal and Arabic Sea, including the Indian Coast) to the long-distance services, including trunk lines both westbound (MEE) and eastbound (NSA) as well as African services are 493,524 TEU (the orange-coloured cells in Table 1), which constitutes a share of almost half of the total transhipped containers. On the other hand, containers with opposite routes (coloured green in Table 1) total 238,941 TEU, which is less than half of the other direction. Intra-regional transhipment (coloured blue) is much lower (137,992 TEU). These estimated results are consistent with the results of the authors' interview surveys with shipping companies in South Asia. Note that transhipment between MEE and other long-distance services is not negligible (181,958 TEU; the purple-coloured cells in Table 1), partly because this might include containers to/from the Arabian Gulf, at which some MEE services call at the ports.

Table 1. Estimated flow of containers transhipped at Colombo Port (TEU)

from \ to	BB-IE	IS	AS-IW	NSA	MEE	EA	WA	Australia	Others	Total
Bay of Bengal and Indian East Coast (BB-IE)	4,544	555	63,370	7,672	178,839	11,077	8,472	6,761		281,289
Indian South Coast (IS)	2,091	0	15,800	56,070	39,231	3,117	6,773			123,083
Arabian Sea and Indian West Coast (AS-IW)	39,520	4,556	7,555	20,730	121,022	13,046	27,475		0	233,905
Northeast and Southeast Asia (NSA)	6,674	60,602	7,892	0	14,994	6,908	0		2,131	99,202
Mediterranean, Europe, and East Coast of North America (MEE)	108,969	21,394	11,622	13,915	65,218	5,044	439	21,138		247,738
East Africa (EA)	4,043	982	615	1	12,150	0	7		34	17,832
West Africa (WA)	11,686	661	3,802	52	8,997	23				25,220
Australia	1,338		5,986	311	40,064	867				48,566
Others				0		140				140
Total	178,866	88,749	116,642	98,750	480,515	40,222	43,166	27,899	2,165	1,076,974

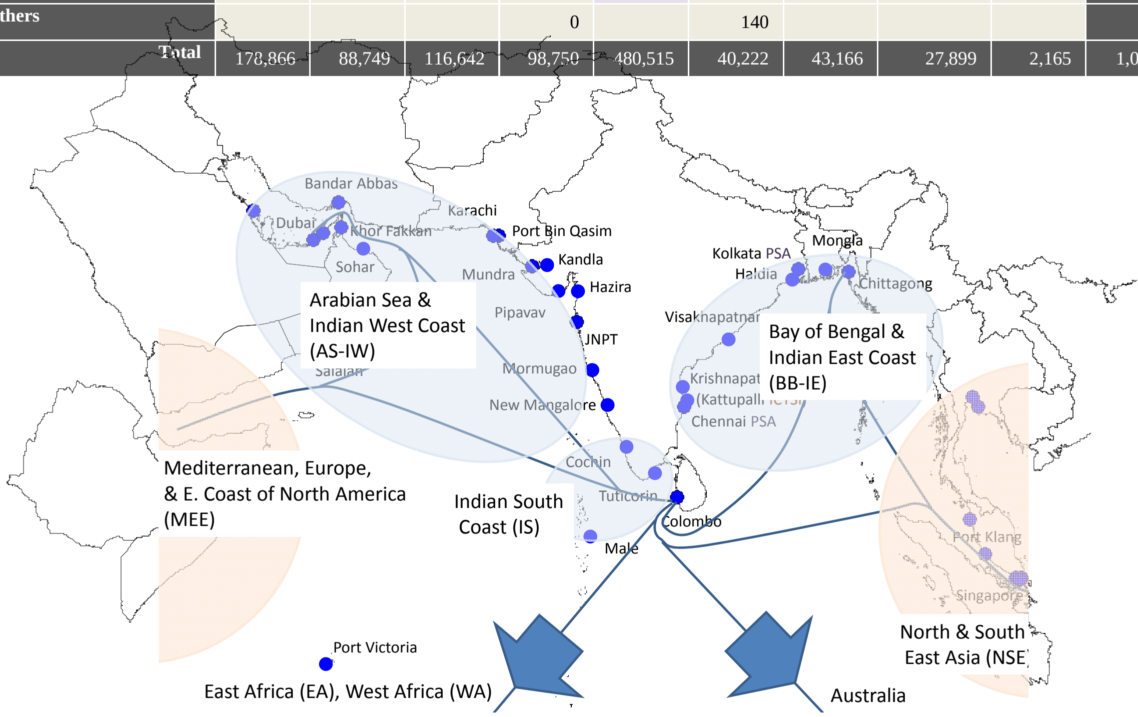


Fig. 6. Main routes of international maritime container shipping in South Asia

5. Simulation using the developed Model

5.1. Improving levels of service at hub ports

The developed model includes one policy variable in terms of level of service in each port: transhipment time, TR_a. Table 2 shows two simulation results; the first scenario assumes when the transhipment time at Colombo Port is improved until reaching the level of other regional major ports, such as Port Klang (Malaysia) and Shanghai (i.e. $TR_{colombo}$ = 24 (hours)); and the second scenario assumes reaching the levels of other major transhipment hubs such as Singapore and Hong Kong (i.e. $TR_{colombo}$ = 12 (hours)), from the base scenario with the current level as shown in Appendix A ($TR_{colombo}$ = 48 (hours)). As shown in the table, the containers transhipped at Colombo Port increase by 17.3% in scenario 1 and 29.7% in scenario 2. Impacts to neighbouring major hub ports are not consistent; however, the total number of containers at these six neighbour hub ports is decreasing under each scenario (i.e. -171,919 TEU in scenario 1 and -401,413 TEU in scenario 2), which is less than the increase in the number of containers transhipped at Colombo Port. Note that these estimation results are acquired with the assumption that the liner service network is not changed at all. In reality, a significant improvement in the level of service at a port will often bring a shift of some liner services to the port in question.

Table 2. Estimation results in the improvement scenarios of level of service in Colombo Port: the amount of containers (TEU, 2013) transhipped at Colombo Port and neighbouring major hub ports

port	Base scenario: $TR_{colombo}$ = 48	Scenario 1: $TR_{colombo}$ = 24			Scenario 2: $TR_{colombo}$ = 12		
	amount of transhipped containers	amount of transhipped containers	difference from base scenario	increasing rate from base scenario	amount of transhipped containers	difference from base scenario	increasing rate from base scenario
Colombo	2,153,949	2,526,498	372,549	17.3%	2,793,460	639,512	29.7%
Singapore	17,119,757	17,104,295	-15,461	-0.1%	16,868,653	-251,104	-1.5%
Tanjung Pelepas (Malaysia)	4,987,757	4,920,776	-66,981	-1.3%	4,861,036	-126,722	-2.5%
Port Klang (Malaysia)	3,716,377	3,607,242	-109,135	-2.9%	3,698,379	-17,998	-0.5%
Dubai (UAE)	1,999,403	1,991,724	-7,680	-0.4%	2,001,744	2,341	0.1%
Sharjah/ Khor Fakkan (UAE)	494,486	508,449	13,962	2.8%	515,286	20,799	4.2%
Salalah (Oman)	1,511,955	1,525,331	13,376	0.9%	1,483,225	-28,730	-1.9%
neighbour hub ports total	29,829,736	29,657,817	-171,919	-0.6%	29,428,323	-401,413	-1.3%

5.2. New transhipment hub in South India

There are many ideas to construct a new transhipment hub in South India, which can compete with Colombo Port, a sole existing hub in South Asia. Not only new terminal constructions of the existing port such as Tuticorin and Cochin, but also constructions of new port such as Vizhinjam and Colachel are included. Among them, a development project of Vizhinjam international container terminal is considered more realistic since it is promoted by Adani Group, who is the strongest conglomerate in Indian port industry and successfully developed Mundra Port from the first that currently becomes the second largest container port in India. On July 2015, the Indian government has issued a letter of award to Adani Group for constructing of the port superstructure and operation of the terminal (Vessel finder, 2015).

In the following simulation (scenario 3), only services operated or co-operated by Shipping Group A (Maersk, eight services in total) is assumed to shift from Colombo to Vizhinjam, which is located in the middle between Tuticorin and Cochin. Note that there is assumed no container shipping demands neither exported from nor imported into Vizhinjam Port, since it locates in very local area in Kerala State. Also, the level of service in both Colombo and Vizhinjam Port (i.e. transhipment time) is assumed to be 12 (hours) as a result of severe competition among them.

Table 3. Estimation results in the new transhipment hub scenario: the amount of containers (TEU, 2013) transhipped at Colombo and Vizhinjam Port

Port	Scenario 2: monopoly by Colombo Port (where $TR_{colombo}$ = 12)			Scenario 3: construction of new transhipment hub (where $TR_{colombo}$ = $TR_{vizhinjamo}$ = 12)					
	amount of transhipped containers			amount of transhipped containers			difference from scenario 2		
	total in all companies	Group A (Maersk)	other groups total	total in all companies	Group A (Maersk)	other groups total	total in all companies	Group A (Maersk)	other groups total
Colombo	2,793,460	787,887	2,005,573	1,963,172	0	1,963,172			
Vizhinjam	-	-	-	657,984	657,984	0			
Two Ports Total	2,793,460	787,887	2,005,573	2,621,155	657,984	1,963,172	-172,305	-129,903	-42,402

The simulation result of scenario 3 is shown in Table 3. Since the containers transhipped by Group A constitutes a share of more than 30% at Colombo Port as shown in Fig. 5, the number of containers transhipped at Colombo Port is predicted to significantly decrease. On the other hand, the number of containers transhipped at Vizhinjam Port is predicted to record almost one-third of that of Colombo Port. Note that the total number of containers transhipped at either Colombo or Vizhinjam Port is smaller compared with the results under scenario 2, for both Group A as well as the total for other groups; this is because several services which are partially slot-chartered by Group A remain to call at Colombo Port, while a service co-operated by Group C (CMA-CGM) calls at Vizhinjam Port under scenario 3.

6. Conclusion

This paper describes a model that the authors developed, in order to predict worldwide container movements on the international maritime shipping network, by applying a network equilibrium assignment methodology, based on the data as of 2013. In this model, every international maritime container in the world which will be transported by major shipping companies is assigned on the maritime shipping network where any liner service of the major shipping companies is provided, and the shipping demand between seaports are given. The model includes 173 seaports which handled more than 500 thousand TEU in 2013, as well as 21 local ports in South Asia and neighbouring regions, which this paper focuses on.

After the convergence of the model calculation is checked, outputs of the model are examined mainly from a viewpoint of the containers transhipped at each port. It is found that the model describes the actual transhipment rate and volume at major hub ports rather well. Also, the container flows transhipped at Colombo Port are summarized by shipping company and combination of regions in which each service is in operation.

By applying the developed model, two kinds of policy simulation are examined. The first simulation shows the result that the number of containers transhipped at Colombo Port increases while those of neighbouring hub ports decreases as the transhipment time at Colombo Port decreases. Also, the results of a second simulation implies that the construction of a new container hub in South India would possibly bring a significant decrease in the number of containers transhipped at Colombo Port, if the new port can successfully attract all services operated by the largest shipping company. Since such a drastic shift from an old hub to new one has occasionally been observed in the real international maritime container shipping market (e.g. the shift to Tanjung Pelepas from Singapore by Maersk in the 1990s), the possibility of the shift to the new port from Colombo cannot be denied.

The forthcoming challenge for the authors is to expand the developed model to include hinterland transport, so that the model can include the choice of gateway port for export or import for each container originated from/attracted into South Asia. The authors already developed a similar model by using the data as of 2010 and applied to Central America (the authors, 2015) and the Lower Mekong Region in Southeast Asia (the authors, 2014). The model development in South Asia will be more challenging compared with these past works, since while the area of South Asia is quite large, there exists less information on hinterland transport in particular. Another challenge is to include a mechanism to structure the liner service network by shipping company. Through such integration with the behaviour of shipping company, infrastructure investments such as deepening existing berths and constructing new berths can be simulated by the model. Because there are a multitude of decision variables, such as ship size, frequency, partner company(ies) and port to call, when structuring the liner service network, an application of a heuristic algorithm, such as a Genetic Algorithm, may be a realistic approach.

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Appendix A.

A.1. Ports included in the model and their throughput and transshipment rate and time

No	Port name	Country	Country/region in the WTS	Annual throughput ('000 TEU)	source	Trans-shipment rate	Trans-shipment time** TR_a(hours)	Lloyd's List ranking (until 110th)
1	Tokyo	Japan	Japan	4,861	b	9.7%*	24	28
2	Yokohama	Japan	Japan	2,888	a	9.7%*	24	48
3	Shimizu	Japan	Japan	499	e	9.7%*	24	-
4	Nagoya	Japan	Japan	2,709	a	9.7%*	24	51
5	Osaka	Japan	Japan	2,485	a	9.7%*	24	60
6	Kobe	Japan	Japan	2,553	b	9.7%*	24	56
7	Hakata	Japan	Japan	868	e	9.7%*	24	-
8	Vladivostok	Russia	South Korea	817	a	9.7%*	48	-
9	**Busan**	**South Korea**	**South Korea**	**17,686**	**a**	**49.5%**	**12**	**5**
10	Yeosu/Gwangyang	South Korea	South Korea	2,285	b	9.7%*	12	63
11	Pyongtaek	South Korea	South Korea	518	a	9.7%*	24	-
12	Incheon	South Korea	South Korea	2,160	a	9.7%*	24	65
13	Dalian	China	China	5,909[#]	a	8.3%*	48	12
14	Tianjin/Xingang	China	China	7,417[#]	a	8.3%*	48	10
15	Yantai	China	China	541[#]	a	8.3%*	48	67
16	Qingdao	China	China	11,182[#]	a	8.3%*	24	7
17	**Lianyungang**	**China**	**China**	3,265[#]	**a**	**65.0%**	**24**	**25**
18	**Shanghai**	**China**	**China**	28,911[#]	**a**	**14.0%**	**24**	**1**
19	**Ningbo**	**China**	**China**	15,967[#]	**a**	**15.0%**	**24**	**6**
20	Fuzhou	China	China	1,206[#]	a	8.3%*	48	73
21	Xiamen	China	China	5,125[#]	a	8.3%*	24	17
22	Shantou	China	China	553[#]	a	8.3%*	48	100
23	**Shenzhen (Yantian)**	**China**	**China**	**10,796[#]**	**c**	**13.0%**	**24**	**3**
24	**Shenzhen (Shekou, Chiwan, Dachan Bay)**	**China**	**China**	**10,644[#]**	**c**		**24**	
25	**Guangzhou (Nansha, Huangpu)**	**China**	**China**	**6,096[#]**	**a**	**8.3%**	**24**	**8**
26	**Hong Kong**	**Hong Kong**	**China**	**22,352**	**a**	**58.6%**	**12**	**4**
27	Keelung	Taiwan	Taiwan	1,613	a	9.7%*	24	53
28	Taipei New Port	Taiwan	Taiwan	1,029	b	9.7%*	24	53
29	Taichung	Taiwan	Taiwan	1,468	a	9.7%*	24	93
30	**Kaohsiung**	**Taiwan**	**Taiwan**	**9,938**	**a**	**46.6%**	**24**	**14**
31	Manila	Philippines	Philippines	3,770	b	9.5%*	48	36
32	Cebu	Philippines	Philippines	555	f1(2012)	9.5%*	48	-
33	Davao	Philippines	Philippines	569	e	9.5%*	48	-
34	Haiphong	Vietnam	Vietnam	1,040	e	9.5%*	48	-
35	Ho Chi Minh	Vietnam	Vietnam	5,542	b	9.5%*	48	24
36	Cai Mep/Vung Tau	Vietnam	Vietnam	1,268	d	9.5%*	24	-
37	Laem Chabang	Thailand	Thailand	6,041	a	9.5%*	24	22
38	Bangkok	Thailand	Thailand	1,505	a	9.5%*	24	88
39	Pasir Gudang	Malaysia	Malaysia	801	f1(2012)	9.5%*	24	-
40	**Tanjung Pelepas**	**Malaysia**	**Malaysia**	**7,628**	**b**	**91.3%**	**12**	**19**
41	**Port Klang**	**Malaysia**	**Malaysia**	**10,350**	**a**	**63.5%**	**24**	**13**
42	Penang	Malaysia	Malaysia	1,238	b	9.5%*	24	102
43	**Singapore/Jurong**	**Singapore**	**Singapore**	**32,579**	**a**	**84.8%**	**12**	**2**
43-1	Yangon (Rangoon)	Myanmar	Other Southeast Asia	233	g	9.5%*	48	-
44	Tanjung Perak (Surabaya)	Indonesia	Indonesia	3,001	b	9.5%*	48	47
45	Tanjung Priok (Jakarta)	Indonesia	Indonesia	6,590	b	9.5%*	48	21
46	Belawan	Indonesia	Indonesia	899	e	9.5%*	48	-
47	Chittagong	Bangladesh	Bangladesh	1,540	b	3.6%*	72	86
47-1	Mongla	Bangladesh	Bangladesh	20	i	3.6%*	72	-
48	Kolkata	India	India	575	a	3.6%*	72	-
48-1	Haldia	India	India	137	f2(2012)	3.6%*	72	-
48-2	Visakhapatnam	India	India	248	f1(2012)	3.6%*	72	-
48-3	Krishnapatnam	India	India	30	f3(2012)	3.6%*	72	-
49	Chennai/Madras	India	India	1,485	a	3.6%*	72	92
49-1	Tuticorin	India	India	469	f1(2012)	3.6%*	72	-
49-2	Cochin	India	India	324	f1(2012)	3.6%*	72	-
49-3	New Manglore	India	India	46	f2(2012)	3.6%*	72	-
49-4	Mormugao	India	India	20	f2(2012)	3.6%*	72	-
50	Jawaharlal Nehru (JNPT)	India	India	4,120	a	3.6%*	72	33
50-1	Hazira	India	India	50	i	3.6%*	72	-

51	Pipavav	India	India	661	a	3.6%*	72	-
51-1	Kandla	India	India	130	f1(2012)	3.6%*	72	-
52	Mundra	India	India	2,156	a	3.6%*	72	61
53	**Colombo**	**Sri Lanka**	**Indian Subcontinent Islands**	**4,306**	**b**	**74.8%**	**48**	**32**
53-1	Male	Maldives	Indian Subcontinent Islands	80	g	3.6%*	72	-
54	Port Mohammad Bin Qasim	Pakistan	Pakistan	768	a	3.6%*	72	-
55	Karachi	Pakistan	Pakistan	1,586	a	3.6%*	72	84
56	St Petersburg	Russia	Russia Baltics	2,514	a	9.7%*	48	57
57	Prince Rupert	Canada	Canada Pacific Coast	539	a	8.3%*	24	-
58	Vancouver BC	Canada	Canada Pacific Coast	2,825	a	8.3%*	24	49
59	Seattle	USA	USA_North Pacific	1,575	a	8.3%*	24	83
60	Tacoma	USA	USA_North Pacific	1,892	a	8.3%*	24	78
61	Oakland	USA	USA_South Pacific	2,346	a	8.3%*	24	62
62	Los Angeles	USA	USA_South Pacific	7,869	a	8.3%*	24	18
63	Long Beach	USA	USA_South Pacific	6,731	a	8.3%*	24	20
64	Manzanillo (Mexico)	Mexico	Mexico Pacific & Central America	2,136	a	8.3%*	24	68
65	Lazaro Cardenas	Mexico	Mexico Pacific & Central America	1,051	a	8.3%*	24	-
66	**Balboa**	**Panama**	**Mexico Pacific & Central America**	**3,064**	**a**	**91.3%**	**24**	**45**
67	**Manzanillo (Panama)/ Cristobal/ Colon**	**Panama**	**Mexico Pacific & Central America**	**3,356**	**a**	**84.6%**	**24**	**40**
68	Puerto Limon	Costa Rica	Mexico Pacific & Central America	1,037	a	25.4%*	48	-
69	Puerto Cortes	Honduras	Mexico Pacific & Central America	571	d	25.4%*	48	-
70	Veracruz	Mexico	North America Atlantic Coast & Carib	867	a	4.1%*	24	-
71	Altamira	Mexico	North America Atlantic Coast & Carib	598	a	4.1%*	24	-
72	San Juan	USA (Puerto Rico)	North America Atlantic Coast & Carib	1,270	b	25.4%*	48	101
73	Caucedo	Dominican Rep	North America Atlantic Coast & Carib	1,083	d	25.4%*	48	-
74	**Kingston**	**Jamaica**	**North America Atlantic Coast & Carib**	**1,672**	**a**	**82.5%**	**48**	**79**
75	**Freeport**	**Bahamas**	**North America Atlantic Coast & Carib**	**1,400**	**b**	**99.0%**	**48**	**94**
76	Houston	USA	North America Atlantic Coast & Carib	1,951	a	4.1%*	24	74
77	Miami	USA	North America Atlantic Coast & Carib	901	a	7.5%*	24	-
78	Port Everglades	USA	North America Atlantic Coast & Carib	928	a	7.5%*	24	-
79	Jacksonville	USA	North America Atlantic Coast & Carib	925	a	7.5%*	24	-
80	Savannah	USA	North America Atlantic Coast & Carib	3,034	a	7.5%*	24	46
81	Charleston	USA	North America Atlantic Coast & Carib	1,601	a	7.5%*	24	82
82	Virginia (Hampton Roads)	USA	North America Atlantic Coast & Carib	2,224	a	7.5%*	24	64
83	Baltimore	USA	North America Atlantic Coast & Carib	705	a	7.5%*	24	-
84	New York/New Jersey	USA	North America Atlantic Coast & Carib	5,467	a	7.5%*	24	26
85	Montreal	Canada	North America Atlantic Coast & Carib	1,357	a	7.5%*	24	97
86	Buenaventura	Colombia	Mexico Pacific & Central America	533	e	9.0%*	48	-
87	Guayaquil	Ecuador	Ecuador	1,518	b	9.0%*	48	87
88	Callao	Peru	Peru	1,856	a	9.0%*	48	75
89	Valparaiso	Chile	Chile	910	a	9.0%*	48	-
90	San Antonio	Chile	Chile	1,197	a	9.0%*	48	103
91	San Vicente(Concepcion)	Chile	Chile	453	d	9.0%*	48	-
92	**Cartagena**	**Colombia**	**North America Atlantic Coast & Carib**	**1,865**	**a**	**56.0%**	**48**	**71**
93	Puerto Cabello	Venezuela	North America Atlantic Coast & Carib	750	e	25.4%*	48	-
94	Manaus	Brazil	Brazil	545	a	10.3%*	48	-
95	Rio De Janeiro	Brazil	Brazil	506	f1(2012)	10.3%*	48	-
96	Santos	Brazil	Brazil	3,446	b	10.3%*	48	38
97	Paranagua	Brazil	Brazil	739	a	10.3%*	48	-
98	Navegantes	Brazil	Brazil	706	d	10.3%*	48	-
99	Itajai	Brazil	Brazil	1,105	a	10.3%*	48	108
100	Rio Grande	Brazil	Brazil	622	a	10.3%*	48	-
101	Montevideo	Uruguay	Other Southeast Coast of South America	804	a	10.3%*	48	-
102	Buenos Aires	Argentina	Argentina	1,651	b	10.3%*	48	81
103	Shahid Rajaee (Bandar Abbas)	Iran	Arabian Gulf	1,763	b	4.1%*	48	76
104	Dammam	Saudi Arabia	Arabian Gulf	1,674	a	4.1%*	48	80
105	Khalifa Bin Salman	Bahrain	Arabian Gulf	430	d	4.1%*	48	-
106	Mina Zayed (Abu Dhabi)	UAE	Arabian Gulf	787	f4(2012)	4.1%*	24	-
107	**Dubai/Jebel Ali**	**UAE**	**Arabian Gulf**	**13,600**	**a**	**50.5%**	**24**	**9**
108	**Khor Fakkan/Sharjah Combined**	**UAE**	**Arabian Gulf**	**3,800**	**b**	**96.0%**	**24**	**35**
108-1	Sohar/Mina Qabos (Mascut)	Oman	Arabian Gulf	331	h(2014)	4.1%*	24	-
109	**Salalah**	**Oman**	**Arabian Gulf**	**3,343**	**a**	**97.5%**	**24**	**41**
110	**Jeddah**	**Saudi Arabia**	**Arabian Gulf**	**4,561**	**a**	**41.0%**	**48**	**29**
111	Aqaba	Jordan	E. Med & Black Sea	883	d	4.1%*	48	-
112	El Sokhna	Egypt	Egypt	511	d	14.7%*	48	-
113	**Port Said**	**Egypt**	**Egypt**	**4,100**	**b**	**86.2%**	**24**	**34**
114	Damietta	Egypt	Egypt	747	d	14.7%*	48	-
115	Alexandria/El Dekheila	Egypt	Egypt	1,508	b	14.7%*	48	89
116	**Tangier/Tangier Med**	**Morocco**	**West Med**	**2,558**	**b**	**96.7%**	**24**	**55**

117	Casablanca	Morocco	West Med	825	a	10.0%*	48	-
118	Las Palmas De Gran Canaria	Spain (Canary Is)	West Med	1,017	a	18.9%*	24	-
119	Ashdod	Israel	East Med & Black Sea	1,182	a	14.7%*	24	104
120	Haifa	Israel	East Med & Black Sea	1,357	a	14.7%*	24	96
121	Beirut	Lebanon	East Med & Black Sea	1,117	a	14.7%*	48	107
122	Mersin	Turkey	East Med & Black Sea	1,367	d	14.7%*	48	95
123	Izmir	Turkey	East Med & Black Sea	720	f5(2010)	14.7%*	48	-
124	**Ambarli/Istanbul/Marport/ Kumport/Haydarpasa**	**Turkey**	**East Med & Black Sea**	**3,378**	**b**	**45.6%**	**48**	**39**
125	Constantza	Romania	East Med & Black Sea	634	d	14.7%*	48	-
126	Odessa/Illichivsk	Ukraine	East Med & Black Sea	535	d	14.7%*	48	-
127	Novorossiysk	Russia	East Med & Black Sea	732	a	14.7%*	48	-
128	**Piraeus**	**Greece**	**East Med & Black Sea**	**3,164**	**b**	**82.0%**	**24**	**43**
129	Koper	Slovenia	Slovenia	600	a	14.7%*	48	-
130	**Marsaxlokk**	**Malta**	**Central Med**	**2,750**	**b**	**95.7%**	**24**	**50**
131	Cagliari	Italy	Central Med	656	d	19.8%*	24	-
132	**Gioia Tauro**	**Italy**	**Central Med**	**3,087**	**b**	**94.5%**	**24**	**44**
133	Leghorn (Livorno)	Italy	Central Med	559	e	19.8%*	24	-
134	La Spezia	Italy	Central Med	1,300	a	19.8%*	24	99
135	Genoa	Italy	Central Med	1,988	a	19.8%*	24	72
136	Marseilles/Fos	France	France Mediterranean	1,098	a	19.8%*	24	109
137	Barcelona	Spain	West Med	1,720	a	19.8%*	24	77
138	**Valencia**	**Spain**	**West Med**	**4,328**	**a**	**49.9%**	**24**	**31**
139	**Algeciras**	**Spain**	**West Med**	**4,345**	**a**	**91.0%**	**24**	**30**
140	Felixstowe	UK	United Kingdom	3,740	b	10.2%*	24	37
141	London (Tilbury)/ Thamesport	UK	United Kingdom	950	e	10.2%*	24	-
142	Southampton	UK	United Kingdom	1,491	b	10.2%*	24	91
143	Liverpool	UK	United Kingdom	650	d	10.2%*	24	-
144	Dublin	Eire	Ireland	517	a	10.2%*	24	-
145	Sines	Portugal	West Med	931	d	10.2%*	24	-
146	Lisbon	Portugal	West Med	549	a	10.2%*	24	-
147	Leixoes	Portugal	West Med	626	a	10.2%*	24	-
148	Bilbao	Spain	France/Spain North Atlantic	607	a	10.2%*	24	-
149	Le Havre	France	France/Spain North Atlantic	2,600	a	10.2%*	24	59
150	Zeebrugge	Belgium	North Sea	2,026	a	10.2%*	24	70
151	**Antwerp**	**Belgium**	**North Sea**	**8,578**	**a**	**28.5%**	**24**	**16**
152	**Rotterdam**	**Netherlands**	**North Sea**	**11,621**	**a**	**31.0%**	**24**	**11**
153	**Bremen/Bremerhaven**	**Germany**	**North Sea**	**5,831**	**a**	**61.0%**	**24**	**23**
154	**Hamburg**	**Germany**	**North Sea**	**9,257**	**a**	**41.9%**	**24**	**15**
155	Gdansk	Poland	North Sea	1,178	a	9.7%*	24	106
156	Kotka	Finland	North Sea	627	a	9.7%*	24	-
157	Gothenburg	Sweden	North Sea	859	a	9.7%*	24	-
158	Abidjan	Cote dIvoire	West Africa	676	d	18.9%*	48	-
159	Tema	Ghana	West Africa	670	d	18.9%*	48	-
160	Lagos/Apapa/Tin Can Island	Nigeria	West Africa	1,106	d	18.9%*	48	-
161	Point Noire	Congo, R.	Central Africa	585	d	18.9%*	48	-
162	Luanda	Angola	Angola	650	d	18.9%*	48	-
163	Cape Town	South Africa	Southern Africa	921	a	21.6%*	24	-
164	Port Elizabeth/Coega	South Africa	Southern Africa	775	a	21.6%*	24	-
165	Durban	South Africa	Southern Africa	2,633	a	21.6%*	24	54
165-1	Maputo	Mozambique	Southern Africa	113	i	21.5%*	48	-
165-2	Nacala	Mozambique	Southern Africa	83	i	21.5%*	48	-
165-3	Dar es Salam/Zanzibar	Tanzania	East Africa	526	g	21.5%*	48	-
166	Mombasa	Kenya	East Africa	875	d	21.5%*	48	-
167	Djibouti	Djibouti	East Africa	780	d	21.5%*	48	-
167-1	Port Victoria	Seychelles	Southern African Islands	41	i	21.6%*	48	-
167-2	Mutsamudu/Moroni	Comoros	Southern African Islands	46	h(2010)	21.6%*	48	-
167-3	Toamasina	Madagascar	Southern African Islands	173	g	21.6%*	48	-
167-4	Pointe des Galets	Reunion (France)	Southern African Islands	213	e	21.6%*	48	-
167-5	Port Louis	Mauritius	Southern African Islands	622	g	54.7%	48	-
168	Brisbane	Australia	Australia	1,085	a	4.8%*	24	-
169	Sydney	Australia	Australia	2,153	a	4.8%*	24	66
170	Melbourne	Australia	Australia	2,492	a	4.8%*	24	58
171	Fremantle	Australia	Australia	703	e	4.8%*	24	-
172	Auckland	New Zealand	New Zealand	819	e	4.8%*	24	-
173	Tauranga	New Zealand	New Zealand	800	a	4.8%*	24	-

Bold: major transshipment ports shown in Drewry Maritime Research (2014a)

Colored ports: newly added in the model as of 2013 (Blue colored: ports which handles containers more than 500,000 TEU; orange colored: local ports in South Asia and neighbor regions)

international containers only;* estimated by the authors based on the average transshipment rate by region shown in Drewry Maritime Research (2014a);** authors' estimation
Source: a. Drewry Maritime Research (2014a); b. Lloyd's List: Top 100 Container Ports 2013; c. China Port Yearbook Publishers (2014); d. Drewry Maritime Research (2014b) – Estimated throughput is available for each container terminal where worlds' major terminal operators are in operation; e. Website of each port or terminal; f. Substituting by the past record: f1. Drewry Maritime Research (2013); f2. Indian Ports Association; f3. KPMG; f4. Lloyd's List; f5. Informa Group (2012); g. World Bank (country-based container throughput); h. Logistics Capacity Assessment website; i. The authors' estimation from various sources.

A.2. Shipping companies included in the model

No.	Group	Group Name	Included Carriers	Annual TEU Capacity (Authors' Estimation from MDS data, '000 TEU)	Share of the world
1	Group A	Maersk	Maersk Line, Norfolkline Ferries, Safmarine Container Lines, MCC Transport, Mercosul Line	17,208	9.9%
2	Group B	MSC	Mediterranean Shipping Co (MSC)	15,994	9.2%
3	Group C	CMA-CGM	CMA-CGM, ANL Container Line, China Navigatrion Co.(CNC Line), Campagrie Marocaine de Navigation (Comanav), Delmas, MacAndrews, FAS, Gemartrans, OT Africa Line, US Lines	13,027	7.5%
4	Group D	Evergreen	Evergreen Marine, Italia Marittima (LT), Jatsu Marine	7,167	4.1%
5	Group E	Hapag-Lloyd	Hapag-Lloyd, CP Ships	4,808	2.8%
6	Group F	APL	APL	4,640	2.7%
7	Group G	CSAV	CSAV (Compania Sud Americana de Vapores), CSAV Norasis Liner Services	2,378	1.4%
8	Group H	Cosco	Cosco Container Lines, Shanghai Panasia	5,854	3.4%
9	Group I	Hanjin	Hanjin Shipping, Senator Lines	4,411	2.5%
10	Group J	CSCL	China Shipping Container Lines (CSCL), Shanghai Puhai	4,480	2.6%
11	Group K	MOL	Mitsui-OSK Lines, Meimon Taiyo Ferry, Shosen Mitsui Ferry	3,706	2.1%
12	Group L	NYK	Nippon Yusen Kaisha (NYK), Tokyo Senpaku Kaisha (TSK), NYK-Hinode Line, NYKLauritzenCool, Kinkai Yusen	4,599	2.7%
13	Group M	OOCL	Orient Overseas Container Line (OOCL)	3,208	1.9%
14	Group N	Hamburg-Sud	Hamburg-Sud, Alianca Transportes Maritimos, Crowley Liner Services, Ybarra y Cia Sudamerica	3,033	1.8%
15	Group O	K-Line	Kawasaki Kisen Kaisha, Kawasaki Kinkai Kisen Kaisha	3,717	2.1%
16	Group P	Yang Ming	Yang Ming Marine Transport Corp, Kuang Ming Shipping	2,825	1.6%
17	Group Q	ZIM	Zim Integrated Shipping Services, Gold Star Line, Laurel Navigation	3,176	1.8%
18	Group R	HMM	Hyundai Merchant Marine	2,998	1.7%
19	Group S	PIL	Pacific International Lines (PIL), Advance Container Line, Pacific Direct Line Ltd	2,025	1.2%
20	Group T	UASC	United Arab Shipping Co (UASC)	2,193	1.3%
21	Group U	X-Press	X-Press Feeders	426	0.2%
22	Group V	Bengal Tiger	Bengal Tiger Line	450	0.3%
23	Group W	OEL	Orient Express Lines	477	0.3%
24	Group X	Emirates	Emirates Shipping Line	2,267	1.3%
25	Group Y	Wan Hai	Wan Hai Lines	186	0.1%
26	Group Z	SCI	Shipping Corp of India	165	0.1%
27	Group AA	DAL	DAL Deutsche Afrika-Linien	366	0.2%
28	Group AB	Hub	Hubline	1,061	0.6%
29	Group AC	RCL	Regional Container Lines	780	0.5%
30	Group AD	Samudera	Samudera Indonesia	219	0.1%
31	Group AE	Shreyas	Shreyas Shipping	766	0.4%
32	Group AF	Simatech	Simatech Shipping	611	0.4%
33	Group AG	STX	STX Pan Ocean Shipping	57	0.0%
34	Group AH	Far Shipping	Far Shipping	84	0.0%
Others				53,831	31.1%
Total				173,192	100.0%

A.3. Shipping companies included in the model

zone	Annual throughput ('000 TEU)			name country/region included in the WTS data	number of ports include d in the model
	A. WTS aggregated	B. Table A.1 aggregated (empty and transhipped containers are excluded)	B/A		
Angola	425	400	0.94	Angola	1
Arabian Gulf	10,336	10,975	1.06	Bahrain; Central Asia; Kuwait; Other Western Asia; Qatar; Saudi Arabia; Southern Arabian Peninsula; United Arab Emirates	9
Argentina	1,203	1,126	0.94	Argentina	1
Australia	4,023	4,656	1.16	Australia; Pacific Islands	4
Bangladesh	1,190	1,142	0.96	Bangladesh	2
Brazil	5,020	5,228	1.04	Brazil	7
Central Med	3,598	2,962	0.82	Italy; Malta; Tunisia	6
Canada Pacific Coast	1,966	2,344	1.19	Canada Pacific Coast	2
Central Africa	610	360	**0.59**	Central Africa – North; Central Africa - South	1
Chile	2,127	1,770	0.83	Bolivia; Chile	3
China	52,004	77,732	**1.49**	China; Hong Kong	14
East Med& Black Sea	7,967	7,429	0.93	Russia Black Sea; South Caucasus; Moldova; Romania; Ukraine; Albania; Bulgaria; Cyprus; Greece; Israel; Other Europe; Other Mediterranean; Turkey	11
East Africa	1,405	1,301	0.93	East Africa –Center; East Africa – North; Kenya	3
Ecuador	772	1,050	1.36	Ecuador	1
Egypt	2,434	2,223	0.91	Egypt	4
France Mediterranean	655	669	1.02	France Mediterranean	1
France/Spain North Atlantic	2,361	2,189	0.93	France Atlantic/North Sea; Spain North Atlantic	2
India	5,053	7,654	**1.51**	India	14
Indian Subcontinent Islands	518	883	**1.71**	Indian Subcontinent Islands	2
Indonesia	6,715	7,215	1.07	Indonesia	3
Ireland	279	353	1.27	Ireland	1
Japan	11,561	11,576	1.00	Japan	7
Malaysia	4,225	4,778	1.13	Malaysia	4
Mexico Pacific & Central America	3,919	4,097	1.05	Mexico Pacific; Belize and Guatemala; El Salvador, Honduras, and Nicaragua; Costa Rica and Panama; Colombia Pacific Coast	7
New Zealand	1,337	1,172	0.88	New Zealand	2
North America Atlantic Coast & Carib	22,264	17,153	**0.77**	Canada Atlantic Coast; Great Lakes (USA); North Atlantic (USA);South Atlantic (USA);Gulf (USA); Mexico Gulf Coast; Greater Antilles, Bahamas, and Bermuda; Lesser Antilles; Colombia Atlantic Coast; Other Northeast Coast of South America; Venezuela	18
North Sea	17,042	19,780	1.16	Austria; Baltics; Belarus; Belgium; Czech Republic; Denmark; Finland; Germany; Netherlands; Norway; Poland; Slovak Republic; Sweden; Switzerland	8
Other Southeast Asia	174	160	0.92	Other Southeast Asia	1
Other Southeast Coast of South America	444	548	1.23	Other Southeast Coast of South America	1
Pakistan	1,430	1,724	1.21	Afghanistan, Bhutan, and Nepal; Pakistan	2
Peru	1,253	1,284	1.02	Peru	1
Philippines	2,016	3,366	**1.67**	Philippines	3
Russia Baltics	1,997	1,724	0.86	Russia Baltics	1
Singapore	3,726	3,763	1.01	Singapore	1
Slovenia	435	389	0.90	Croatia; Hungary; Slovenia	1
South Korea	10,801	10,761	1.00	South Korea; Other Northeast Asia; Russia Pacific	5
Southern Africa	2,452	2,697	1.10	East Africa – South; Southern Africa	5
Southern African Islands	287	496	**1.73**	Southern African Islands	5
Taiwan	5,652	6,852	1.21	Taiwan	4
Thailand	6,105	5,190	0.85	Thailand	2
United Kingdom	3,717	4,662	1.25	United Kingdom	4
USA_North Pacific	2,474	2,415	0.98	North Pacific (USA)	2
USA_South Pacific	11,052	11,806	1.07	South Pacific (USA)	3
Vietnam	4,755	5,399	1.14	Vietnam	3
West Africa	3,309	1,511	**0.46**	Benin and Togo; Burkina Faso, Mali, and Niger; Cote dIvoire; Ghana; Nigeria; Other Western Africa; Senegal	3
West Med	4,773	5,684	1.19	Algeria; Morocco; Portugal; Spain Med/South Atlantic	9
Total	237,861	268,648	1.13	**117 zones**	**194**

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