CONTAINER TRANSPORTATION NETWORK EQUILIBRIUM ANALYSIS CONSIDERING DRAFT OF VESSEL

Syafi'i
Jurusan Teknis Sipil, Fakultas Teknik, Unversitas Sebelas Maret, Jl. Ir. Sutami No. 36 A, Kentingan, Surakarta. Telp: 0271- 634524.
Email : syafii@uns.ac.id

Abstract

This paper analyzes container transportation network equilibrium considering draft of vessels. Concept of load factor (λ) of ship is included in the model. Three players are considered, i.e. port administrator, ship companies (carriers), and shippers. Interaction of these players leads to Nash equilibrium problem. The result of the model calculation indicates that Hong Kong and Singapore port dominates container throughput in the world and the big vessel (3000 - 6000 TEU) is dominant in these ports. Conversely, the smaller port with depth less than 15 m dominated by 1000 TEU vessels. The result is inline with the reality. The other finding from the study is 6000 TEU vessels can enter port with depth less than 15 m such as port of Shanghai. Again, it is inline with reality. Validation of the model shows that coefficient of determination (R^2) is 0.95. It indicates the model provides good accuracy.

Keywords:
Container transportation, Nash Equilibrium, Network

INTRODUCTION

In the process of globalization, containerization is continuing to make a vital contribution to the rapidly growing international trade. It provides shippers with safe, easy and relatively cheap access to international markets in any part of the world through a highly integrated, efficient network of trunk routes and feeder services utilizing trans-shipment opportunities. Since the introduction of containerization, container throughput in the world has continuously increased due to economic growth, and several other factors including container penetration of general cargo trades, the movement of empty containers and increased trans-shipment. Owing to a combination of these factors, container throughputs have increased even in periods of regional recession, as was the case during the Asian economic crisis.

The sustained growth of container trade has been accompanied by the globalization of container shipping market. Severe competition among container shipping has forced owners to implement innovative, productivity-enhancing and cost-cutting strategies. Successively larger vessels have been employed on mainline trades. New service patterns have evolved, including 'Round-the-World' and 'Pendulum' services. In their search for cost reduction and faster transit times, lines have reduced the number of port calls, leading to the growth of 'hubs' or 'load centres' and the evolution of feeder networks. Very large ('mega') carriers' are emerging and lines are entering into various types of strategic alliance. Currently, 4,000-6,000 TEU (twenty feet equivalent units) vessels already dominated major Asian deep-sea trades.

Since 2002, ships in excess of 6,500 TEU have come into operation on Asian routes and some carriers are considering constructing and deploying even larger ships. Increased concentration in liner shipping makes it vitally important for a port to keep its existing shipping company tenants. However, increased vessel size gives shipping lines incentives to look for ports with deeper access channels, berthing areas, and higher dockside and terminal efficiency to reduce the turn-around-time. It will also reduce the number of port calls to maximize the productivity of "mega vessel". These factors not only force existing ports to invest in capacity improvement, but also provide opportunities for building new ports at potentially attractive sites. Therefore, modeling of container transportation network is important to predict the future liner shipping decision. Of course, the prediction is very useful for port authority to prepare the best strategy.

Some researchers have been concerned with container transportation network. Perakis and Jaramillo (1991) and Jaramillo and Perakis (1991) developed a linear programming model for a routing strategy to minimize total fleet operating and lay-up cost during a planning horizon. They assumed several predetermined routes (sequences of ports of call) and developed a model to assign each ship to some mix of the predetermined routes. Rana and Vickson (1991) presented nonlinear programming models.

They tried to maximize total profit by finding an optimal sequence of ports of call for each ship.

Imai and Papadimitrious (1996), Osman, et al., (1997), and Ieda et al., (1998a, 1998b, 1999) focused on the carriers's behavior of port choice and failed to model transportation tariffs. Also they did not consider the domestics shippers' behavior or management policy of port administrators. In the actual market, three kinds of player exist: carriers; shippers, and port administrators. At least, market prediction must give equilibrium solution of behaviors of carriers and shippers under various port management policies. From this point of view, Kuroda et al (1999, 2000, 2001), Kuroda and Yang (1997a, 1997b), Yang (1999) developed different models of container marine transportation. Mauro, et al (2002) presented a successful application of integer linear programming to support the decision-making process of assigning ships. However, the above researchers did not consider the draft of vessels (vertical distance between the waterline and the keel). Why should port characteristics (berth depth) be considered on maritime transportation network model ? Theoretically, 6000 TEU vessels will enter port with depth more than 15 m. However, in the real market, 6000 TEU ship can enter port with depth of 12m (e.g., Shanghai port). Why the phenomenon occurs? In this case, carriers do not use full capacity of 6000 TEU ship in order to ship can enter the port. Therefore, Concept of load factor (λ) of ship should be included on maritime transportation network model. In the previous model, load factor for each ship type is fixed. This paper try to accommodate concept of load factor.

The aim of this paper is to analyze container transportation network equilibrium considering draft of vessels. The rest of this paper is organized as follows. Section 2 describes model formulation. Section 3 provides numerical example. Finally, conclusion is given in section 4.

METHOD

In the real container market, three players should be considered, i.e. port administrator, ship companies (carriers), and shippers. Port administrators create strategy to take advantage of the maritime transportation market of the prosperity of their port by constructing of deep-water container berths, increasing port capacity, cargo handling charge, installing the electric data information system, etc. In accordance with port administrators' strategy, Carriers also create strategy in order to survive in the market by choosing route, vessel type and service frequency on each route, taking into account the inter-port cargo volume. The strategy of carriers aims to minimize their total transportation cost. It should be noticed that the strategy of carriers is constrained by the policy of port administrator. In other side, shipper may choose their port and schedule choice to minimize the total transportation cost and loss of cargo value due to waiting at a port under a given inland transportation network and transportation service presented by carriers. Therefore, there is strong correlation among port administrator, carriers, and shippers. In the market context, this condition will leads to Nash equilibrium problem. Nash Equilibrium is a set of strategies such that player believe that it is doing the best it can, given the strategy of the other player (Damme, 1991).

The concept of the model is shown in Figure 1. In this study, a route that connect specific port (A, B, C, D) is called as "link" (*l*). Carriers can choose which port as loading port and unloading port; and they also can choose vessel type (*m*), service frequency (*f*), and container volume (*x*). Shippers can choose which link of land transportation (*l*') and port to send a container from origin zone *i* to destination zone *j*.

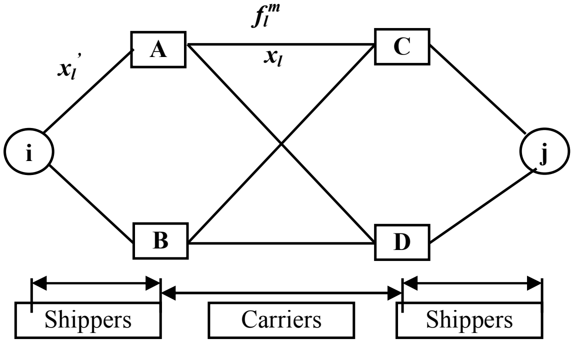

Figure 1. Concept of the model

Assumptions

The following assumptions are included in the study:

- The market is perfectly competitive.
- There are so many carriers and shippers in the market.
- Shippers can choose the loading and unloading port and they can't choose marine transportation route.
- Carriers and shippers have perfect information about market.
- Carriers can choose some classes of vessel size.
- Navigation time on a specific link is same for different ship size. In the numerical example, 1000 TEU, 3000 TEU and 6000 TEU vessels are considered.
- The O.D cargo volume is a priori given and not influenced by services provided by carriers.
- Carriers have to transport all the O.D. cargo.

Carrier's Behavior

As stated earlier, carriers create strategy in order to minimize total operation cost by choosing route network among port including service frequency and vessel size. Therefore, decision variables of carriers are, choosing service frequency of a vessel of type *m* on link *l* (f_l^m) and container volume transported on link *l* (x_l). Mathematically, it can be formulated as follows:

$$\underset{f_l^m, x_l}{Min}\ Z_c = \sum_l \sum_m C_l^m \left(f_l^m, x_l\right) \text{........................} [1]$$

$$C_l^m = F_l^m \left(f_l^m\right) + \sum_h \delta_l^h PC_l^m f_l^m + \sum_h \delta_l^{hL} x_l CW_h \quad [2]$$

$$F_l^m = \left\{T_l^m \left(MFO_l^m + CA_l^m\right) f_l^m\right\} \Phi\left(f_l^m\right) \text{...........} \ [3]$$

$$\Phi\left(f_l^m\right) = \theta_1 \left\{\frac{\sum_l \sum_m \delta_l^h \lambda_l^m f_l^m CP_l^m}{VC_h}\right\}^{\theta_2} \text{..............} [4]$$

Subject to

$$\sum_i \sum_j \sum_r \delta_{ij}^{rl} x_{ij}^r = x_l \quad \text{for } \forall\ l \text{.......................} [5]$$

$$x_l \le \sum_m \delta_l^m \lambda_l^m f_l^m CP_l^m \quad \text{for } \forall\ l \text{...................} \ [6]$$

$$\sum_l \sum_m \delta_h^l \delta_l^m \lambda_l^m f_l^m CP_l^m \le VC_h \text{......................} \ [7]$$

$$\sum_l \delta_h^l \delta_l^m \lambda_l^m f_l^m CP_l^m \le VC_h^m \quad \text{for } \forall\ h \text{................} [8]$$

$$f_l^m \ge 0 \quad \text{for } \forall\ l \text{..................................} \ [9]$$

where

Z_c = total cost

C_l^m = total operation cost of vessel of type *m* on link *l*

f_l^m = service frequency of a vessel of type *m* on link *l*

T_l^m = navigation time of a vessel of type *m* on link *l*

F_l^m = total navigation cost of vessel type *m* on link *l*

δ_l^h = croneker's delta, takes 1 when the port *h* is included on link *l*, otherwise takes zero

δ_l^{hL} = croneker's delta, takes 1 when the port *h* is used as loading and unloading port on link *l*, otherwise takes zero

MFO_l^m= fuel cost of a vessel of type *m* on link *l*

CA_l^m = ship cost of a vessel of type *m* on link *l*

PC_l^m = port charge of type *m* connected with link *l*

x_l = container volume transported on link *l*

CW_h = loading and unloading charge at port *h*

$\Phi(f_l)$ = congestion cost

$\theta 1$, $\theta 2$= parameter

CP_l^m = maximum loading capacity of a vessel of type *m* on link *l*

λ_l^m = load factor of a vessel of type *m* on link *l*

VC_h = maximum capacity of port *h*

Function $\Phi(f_l)$ in equation (3) means an additional cost coefficient due to congestion as increases of service frequency at port *h* expressed by equation (4). Eq. (5) means that container volume from zone *i* to zone *j* using link *l* of route *r* should equal to the total container flowing on link *l*. Eq. (6) represents link capacity constraint. Eq. (7) and Eq. (8) represent the port capacity constraints. Eq. (9) is a non-negative constraint for service frequency.

Shipper's Behavior

Strategy of shippers is to choose the loading and unloading port in order to minimize total transport cost. Therefore, decision variable of shipper is to send container volume (x_{ij}^{qs}) from zone *i* to zone *j* by using port *q* as loading port (exporting port) and port *s* as unloading port (importing port). Mathematically, shipper's behavior can be stated as follows:

$$\underset{x_{ij}^{qs}}{Min}\ Z_u^{ij} = SC_k \Gamma\left(x_{ij}^{qs}\right) \text{..................... ....} \ [10]$$

$$SC_k = \delta_k^r \left\{\sum_l \delta_r^l (TV * T_l)(1 + \xi(x_l)) + P_r\right\} + \delta_{l'}^k C_{l'} \text{..} [11]$$

$$\xi(x_l) = \rho_1 \left\{\frac{x_l}{\sum_m \lambda_l^m CP_l^m f_l^m}\right\}^{\rho_2} \text{.....................} [12]$$

Subject to

$$\sum_q \sum_s x_{ij}^{qs} = X_{ij} \quad \text{for } \forall i,j \text{..........................} [13]$$

$$\sum_i \sum_j \sum_q \sum_s \delta_{ij}^{lqs} x_{ij}^{qs} = x_l \quad \text{for } \forall l \text{.....................} [14]$$

$$\sum_i \sum_j \sum_q \sum_s \delta_{ij}^{l'qs} x_{ij}^{qs} = x_{l'} \quad \text{for } \forall l' \text{.................} [15]$$

$$x_{ij}^{qs} \ge 0 \quad \text{for } \forall i,j,q,s \text{...........................} \ [16]$$

where

Z_u^{ij} = shipper's total cost between origin i and destination j

SC_k = shipper's total cost using route k

X_{ij} = OD cargo volume from zone *i* to zone *j*

$$\Gamma(.) \begin{cases} = 1 \ \ when \ \ x_{ij}^{qs} > 0 \\ = 0 \ \ otherwise \end{cases}$$

$$\delta_k^r \begin{cases} = 1 \ \ when \ \ \text{route r is included in route k} \\ = 0 \ \ otherwise \end{cases}$$

$$\delta_{l'}^k \begin{cases} = 1 \ \ when \ \ \text{route } l' \text{ is included in route k} \\ = 0 \ \ otherwise \end{cases}$$

$$\delta_{ij}^{lqs} \begin{cases} = 1 \ \ when \ \ \text{port } q \text{ and } s \text{ in icluded on link } l \\ = 0 \ \ otherwise \end{cases}$$

$$\delta_{ij}^{l'qs} \begin{cases} = 1 \ \ when \ \ \text{port } q \text{ and } s \text{ in icluded on link } l' \\ = 0 \ \ otherwise \end{cases}$$

TV = time value of cargo
T_l = total travel time of link l
P_r = marine transportation tariff of route r
$C_{l'}$ = inland transportation cost of link l'
$\xi(x_l)$ = link congestion cost function
CP_l = total loading capacity of link l
f_l^m = service frequency of vessel of type m on link l
ρ_1, ρ_2 = parameter

In Eq. (11), function $\xi(x_l)$ denotes the additional cost coefficient due to congestion at port connected with link l as expresse by Eq. (12). Eq. (13) is constraint of OD cargo volume. Eq. (14) and (15) refers to constraint for container volume on link on a link. The equilibrium tariff is given by:

$$P_r = \sum_l \delta_r^l \frac{C_l}{x_l} \quad \text{for } \forall\ l \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [17]$$

RESULTS AND DISCUSSION

To examine the accuracy of the model, numerical example is carried out. Some major ports in the world which have significant container volume throughput are included. List of these ports is shown in Table 1.

Table 1. Port and hinterland

No.	Port	Hinterland
1	Keihin (Tokyo and Yokohama)	Japan
2	Nagoya	
3	Hanshin (Osaka and Kobe)	
4 *	Kitakyushu, Shimonoseki, Hakata	
5	Busan	South Korea
6	Kaohsiung	Taiwan
7 *	Shanghai	Middle/South China
8	Hong Kong	Hongkong
9	Singapore	Singapore
10 *	Tanjung Priok	Indonesia
11	Port Klang	Malasyia
12 *	Manila	Philipina
13 *	Laem Chabang	Thailand
14	Los Angeles	N.A/Canada
15	Rotterdam	Europe

Note: * indicates port with depth less than 15 m

Some ports with depth less than 15 m are included to prove the concept of load factor. The result of the model calculation indicates that Hong Kong and Singapore port dominated container throughput in the world and the big vessel (3000 - 6000 TEU) is dominant in these ports. Conversely, the smaller port with depth less than 15 m dominated by 1000 TEU vessels as shown in Table 2. The result is inline with the reality. Currently, the two biggest ports previously mentioned are the hub port which serve the smaller port. An example, more than 70% container from and to Indonesian port use Singapore port as transshipment port. Therefore, most of container throughput in Hong Kong and Singapore port is transshipment as shown in Table 3. The important finding from the study is 6000 TEU vessels can enter port with depth less than 15 m such as port of Shanghai. Again, this result is inline with reality. If we did not consider the concept of load factor, of course the result will provide different result which differs from reality.

Table 2. Number of vessels on each port

No	Port Name	Vessel type 1000 TEU	3000 TEU	6000 TEU
1	Keihin	108	1920	200
2	Nagoya	140	286	66
3	Hanshin	131	1173	110
4	*Kit, Shim, Hak*	*215*	*91*	*33*
5	Busan	312	467	1100
6	Kaohsiung	40	1039	174
7	*Shanghai*	*763*	*781*	*242*
8	Hong Kong	1377	1229	1221
9	Singapore	398	274	2115
10	*Tanjung Priok*	*388*	*388*	*244*
11	Port Klang	464	328	227
12	*Manila*	*106*	*75*	*103*
13	*Laem Chabang*	*380*	*369*	*112*
14	Los Angeles	1554	964	660
15	Rotterdam	0	0	1039

To validate the model we compare container transshipment on specific port which has transshipment data as shown in Table 4 and Figure 2. Figure 2 shows that coefficient of determination (R^2) is 0.95. The result indicates the model provide good accuracy.

Table 3. Container throughput (TEU)

No.	Port Name	Export (TEU)	Import (TEU)	Tranship (TEU)	Pass (TEU)
1	Keihin	1,575,789	2,657,409	1,154,876	2,117,466
2	Nagoya	867,595	723,626	423,968	487,902
3	Hanshin	816,469	1,355,698	673,984	1,493,749
4	Kit, Shim, Hak	382,092	559,601	178,936	401,256
5	Busan	2,194,084	2,036,346	1,198,279	3,151,354
6	Kaohsiung	2,241,737	1,862,187	0	0
7	Shanghai	3,027,020	2,324,898	0	0
8	Hong Kong	6,143,814	5,772,629	5,592,450	6,753,984
9	Singapore	1,984,562	2,045,773	8,765,924	8,074,254
10	Tanjung Priok	1,011,060	1,184,955	0	0
11	Port Klang	1,871,988	1,748,795	0	0
12	Manila	582,765	665,925	0	0
13	Laem Chabang	1,298,913	1,181,587	0	0
14	Los Angeles	6,682,194	7,899,196	0	0
15	Rotterdam	5,653,951	4,315,408	0	0

.Table 4. Comparison of container transshipment between model and data

No.	Port Name	Transhipment	
		Model	Data
1	Keihin	1,154,876	1,210,138
2	Nagoya	423,968	492,615
3	Hanshin	673,984	864,068
4	Kit, Shim, Hak	178,936	174,569
5	Busan	1,198,279	3,309,957
6	Hong Kong	5,592,450	6,183,557
7	Singapore	8,765,924	13,009,665

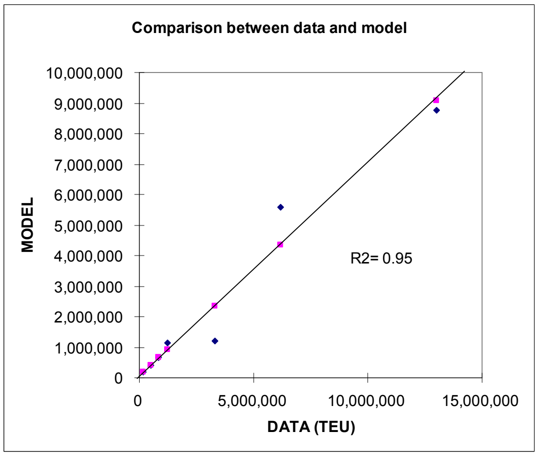

Figure 2. Comparison between data and model of Transshipment

CONCLUSION

This paper analyzes container transportation network equilibrium considering draft of vessels. Concept of load factor (λ) of ship is included in the model. In the real container market, three players should be considered, i.e. port administrator, ship companies (carriers), and shippers. Port administrators create strategy to take advantage of the maritime transportation market of the prosperity of their port. In accordance with port administrators' strategy, Carriers also create strategy in order to survive in the market by choosing route, vessel type and service frequency on each route. In other side, shipper may choose their port and schedule choice to minimize the total transportation cost and loss of cargo value due to waiting at a port under a given inland transportation network and transportation service presented by carriers. In the market context, this condition will leads to Nash equilibrium problem. The result of the model calculation indicates that Hong Kong and Singapore port dominates container throughput in the world and the big vessel (3000 - 6000 TEU) is dominant in these ports. Conversely, the smaller port with depth less than 15 m dominated by 1000 TEU vessels. The result is inline with the reality. Currently, the two biggest ports previously mentioned are the hub port and serve the smaller port. The other finding from the study is 6000 TEU vessels can enter port with depth less than 15 m such as port of Shanghai. Again, this result is inline with reality. If we did not consider the concept of load factor, of course the result will provide different result which differs from reality. Validation of the model shows that coefficient of determination (R^2) is 0.95. The result indicates the model provides good accuracy.

REFERENCES:

Damme, E.V, 1991, "Stability and Perfection of Nash Equilibria", 2^{nd}, Springer – Verlag.

Ieda, H. et al, 1998a, “Container Flow Model and Application in Asian Region”, *Journal of Infrastructure Planning*, JSCE, No. 16, pp. 469-480.

Ieda, H. et al, 1998b, “A Simulation Model of International Container Shipping Including Domestic Land and Feeder Transportation”. *Proceeding of Infrastructure Planning*, JSCE, No. 21 (2), pp. 717-728.

Ieda, H. et al, 1999, “Container Flow Model Considering of Domestic Shippers’ Behavior in Japan”, *Journal of Infrastructure Planning*, JSCE, pp. 731-741.

Imai, A., and Papadimitrious, 1996, “Port Choice for Hubs in the Container Liner Networks of Eastern Asia”, Proc. of the 1st JSPS-NUS *Seminar on Integrated Engineering*, pp. 115-124.

Jaramillo, D.I and Perakis, A.N, 1991, “Fleet deployment optimization for liner shipping, Part 2. Implementation and result”. *Maritime Policy and Management* 18,235-262

Kuroda, K., and Yang, Z., 1997a, “Port Management Policy and the Influence on Behavior of Liner Shipping Company and Shippers”, Journal of the Eastern Asia Society for Transportation Studies, Vol. 2, No. 1, pp. 73-86.

Kuroda, K., and Shao, Y., 1997b, “Impact of Construction of An International Container Terminal at Shanghai on the Container Cargo Flow in Asian Pacific Region”, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 2, No. 1, pp. 115-126.

Kuroda, K., Takebayashi, M., Tsuji, T., and Mutto, M., 1999, “Influence of Port Management Policy on the Behavior of Container Liner Ship Company and Shippers”*, Journal of the Eastern Asia Society for Transportation Studies,* Vol. 3, No. 2, pp. 127-138.

Kuroda, K., Takebayashi, M., Muto, M., Okubo, T., and Tsuji, T. , 2000, “Impact Study on Introduction of Post-panamax Container Cargo Vessel to the Asian-Pacific-European Maritime Transport Market”, *Journal of JSCE*, No. 667/IV-50, pp. 123-136, 2001.1.

Kuroda, K., Takebayashi, M., Muto, M., Okubo, T., and Tsuji, T., 2001, “Development of Model for Forecasting International Container Cargo Flow and Its Application to Major Asian-Pacific Services Routes”, *Journal of JSCE*, No. 653/IV-48, pp. 117-131, 2000.7.

Moura, M.C and Pato, M.V., 2002, “Ship Assignment with Hub and Spoke Constraints”. *Maritime Policy and Management* 29 (2), 135 - 150

Osman, M,A., & Inamura, H., 1997, “Port Choice Seselction Based on Cargo Physical Distribution (Containerization) for Export Promotion”. *Journal of EAST*, 2(2), 129-139.

Perakis, A.N. and Jaramillo, D.I., 1991, “Fleet Deployment Optimization for Liner Shipping, Part 1. Background, problem formulation and solution approaches”. *Maritime Policy and Management* 18,183-200

Rana, K and Vickson, R.G, 1991, “Routing Containerships Using Lagrangean Relaxation and Decomposition”. *Transportation Science* 25, 201-214

Yang Zan , 1999, “Analysis of Container Port Policy by The Reaction of an Equilibrium Shipping Market”. *Maritime Policy and Management* 26 (4), 369 - 381