CONTAINER PORT LOCATION STRATEGY BASED ON DOMESTIC PORT CHOICE MODELING AND OPTIMAL LINER ROUTING*

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1.0 INTRODUCTION

The decision for container ports to seek hub or spoke status are based on the suitability (or otherwise) of their facilities for deep sea vessels, their locations and inland links, the extent of port competition and the size of their hinterlands. Many ports are effectively a mixture of door-to-door and feeder ports, or may have some hub-activities as well.

Malaysian ports also have the hub or spoke quandary as to the dominance of Singapore as transshipment hub handling 60% in volume of Malaysia's foreign trade. Singapore's deep water, world class efficiency, extensive range of feeder services, and state-of-the-art facilities curbed the ambition to win a greater slice of transshipment volume to a degree. Albeit, one of the significant factors in port successful equation is its location, natural and developed, which will be the focus of the paper by introducing two models -local port choice and containerized liner routing. The purpose of introducing these two models is to establish and proposed a broader concept of port planning based on the compatibility of domestic planning and that of carriers and shippers behavior requirement pertinent to Malaysia's ports and other regional ports.

No similar study was done dealing with ports' location integrating the dual models mentioned earlier. Despite the abundance of studies on modal and travel choice, most are related to passenger demand analysis[1]- the source of reference for freight analysis (port choice modeling). Earlier study of port choice selection[2] was carried out but only limited to origin and destination analysis without attempting any mathematical model. The port choice model introduce here is an extension to the above work. Some attempts to analyze the ship routing and scheduling were done in the past, only a few of them related to container ships. Ronen[3,4] provides an extensive review until 1993. Al-Kazily[5] models containerized shipping through economic perspective without routing. Strategies of containerized liner services using mathematical programming given by Imai et al [6] is more relevant to the paper.

**Keywords*: Freight Flow, Terminal Planning

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2.0 SCOPE AND APPROACH

The general framework of the study is given by **Fig. 1**. The details of each model are further discussed in the succeeding section.

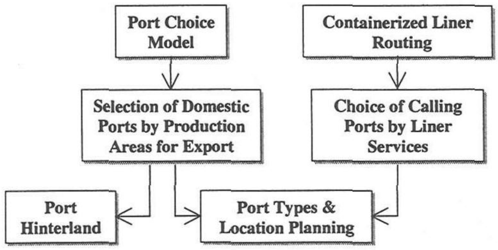

Fig. 1: General Framework of Study

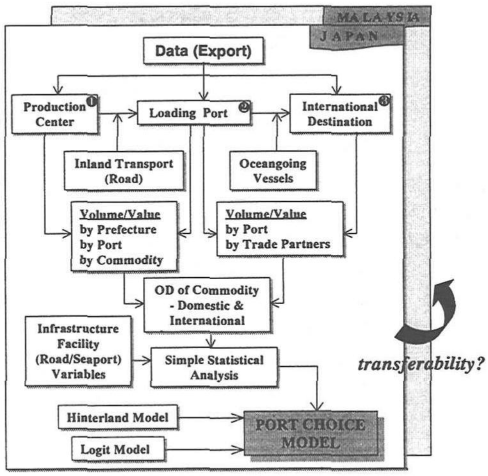

Fig. 2: Study Flow of Port Choice Model

3.0 PORT CHOICE MODEL

Analyzing domestic freight flow OD (production center to loading port) is extremely valuable to transportation planners. This section focus on:

1. variations (volume and value) of containerized cargo, the commodity types passing through a port and its hinterland,
2. variables related to port and road facility and their correlation on export volume/value,
3. application of logit model

Fig. 2 shows the steps of analysis adopted. Initially, Japan is taken as the case study due to the availability of data and facing similar problems (transshipment using foreign ports). The approach adopted for Japan is similarly applied to Malaysia. Transferability of parameters is another aspect to investigate. Certain steps in the figure are further explained below.

3.1 Data Base and Selection of Variables

Summary of database is given in **Table 1** and the related variables (port and road facilities) having impact of varying degrees to the selection of ports is as per **Fig.3**.

Table 1: DataBase

Country	OD Observations	Port Choice	Remark
Japan	418	24	1993 Survey
Malaysia	19	5*	Questionnaire

* inclusive of Singapore

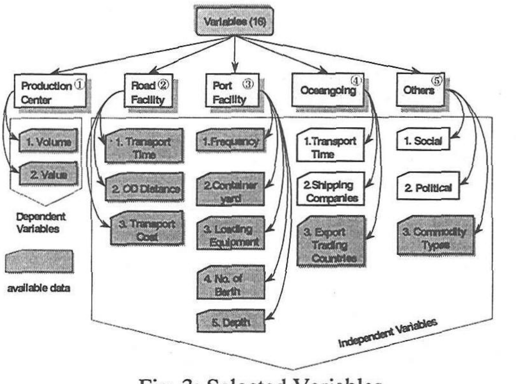

Fig. 3: Selected Variables

3.2 Logit Model – Solution Procedure

Logit model is a good way of examining the determinants with dependent variable (two or more discrete choices). For given observation on X_i, probability that a response Y will be in category j is given by the multinomial logistic probabilities below:

$$P_{ji} \equiv P(Y = j \mid X_i) = \frac{\exp[b_j^{'} X_i]}{D_i} \text{ ....(1)}$$

whereby $D_i = \sum_{j=1}^{J} [\exp(b_j^{'} X_i)]$

D = normalizing denominator that weighs the probability terms so as they add to 1.

J = number of alternatives available; j = 1,.....,J

X_i = represents the values taken on by the K independent variables; $b_j^{'} X_i$ represents $\Sigma b_{kj} X_{ik}$

b_j : coefficients of the unknown parameters

Maximizing the likelihood function expression and using MLEs principle to yield MLE estimators (Eq.2):

$$\Lambda = \sum_{i=1}^{M} \sum_{j=1}^{J} N_{ji} \cdot \ln \left[\frac{\exp(b'_j X_i}{\sum_{h=1}^{J} \exp(b'_h X_i} \right] \rightarrow \max \text{ ....(2)}$$

The values of b can be obtained through iterative algorithm. In this study however, logit model can be further characterized involving 3 types:

i. Conditional logit - choice-specific data (conditional variables) and coefficients are equal over all choices
ii. Multinomial logit – chooser-specific data (multinomial variables) and coefficients vary over the choices. The model is also identified by normalizing the multinomial coefficients of the first choice is to zero.
iii. Mixed logit - involves both types of data and coefficients of i) and ii).
Example of a model with 3 choices:

$V_1 = a_1 + Xb_1 + Z_1 g + e_1$

$V_2 = a_2 + Xb_2 + Z_2 g + e_2$

$V_3 = a_3 + Xb_3 + Z_3 g + e_3$, where;

X -multinomial variables with coefficients b_1, b_2, b_3

Z -conditional variables with coefficients g

If the disturbances e1, e2, e3 have the Generalized Extreme Value distribution, then the observed choice probabilities have the form:

$$\mathrm{Pr}ob(i) = \frac{\exp(a_i + Xb_i + Z_{ig})}{\sum_j (\exp(a_j + Xb_j + Z_{jg}))} \text{ ....(3)}$$

Three model types of models were tested:

i. 1st model- port specific intercepts only
ii. 2nd model- intercepts + distance + time + cost
iii. 3rd model- intercepts + all 12 variables

3.3 Main Results of Analysis

i. Correlation analysis- distance, time, and cost show high correlation while others of the range between 0.0023-0.9120.
ii. Parameter estimation- 2nd model gives a better results since 3rd model produced zero t-stats due to singularity of variables related to port facility. To improve the results, the 24 ports' choice is streamed to 12 ports by selecting OD pair having volume (share) > 10%. Results of parameter estimation are as **Tables 2-3.** Each probabilities $(i - j)$ were calculated using (4).
iii. By taking 10% volume share, hinterland can be clearly demarcated as shown by **Fig. 4.**

Transferability and updating of coefficients [7] are invoked when models estimated in one area to predict in other area due stringent resource constraints (time and lack of data).

Test statistics equation

$TS_M(\theta_J) = -2[LL_M(\theta_J) - LL_M(\theta_M)]$..................(4)

$LL_M(\theta_J)$ = log likelihood (LL) of Japan coefficients on the Malaysia (Msia) data

$LL_M(\theta_M)$ = LL of Msia coefficients on Msia data

Updating Procedures for Model Parameters

Using Eq. 5 which can be represented by **Fig. 5.**

$$\begin{pmatrix}\text{Posterior probability of} \\ \theta \text{ given the sample}\end{pmatrix} = C \times \begin{pmatrix}\text{likelihood of the} \\ \text{sample given } \theta\end{pmatrix} \times \begin{pmatrix}\text{prior probabilityof } \theta\end{pmatrix} \text{.......(5)}$$

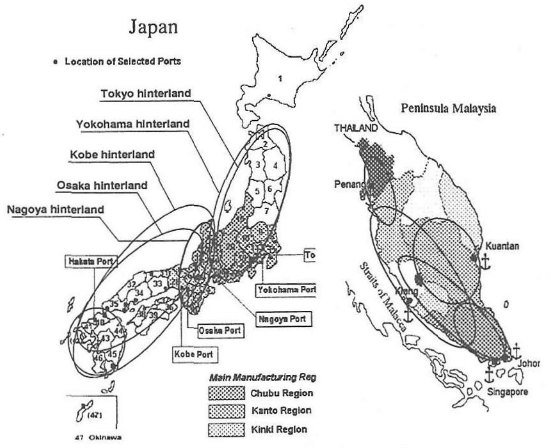

Fig.4: Port Hinterland Demarcation

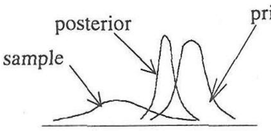

Fig.5: Single Parameter Case

Table 2: Parameter Estimation-Japan

Port	All Data		Volume(share)>10%	
	Parameter	t-stats	Parameter	t-stats
A1	7.00167	60.6051	0.605398	16.8545
Var 1	0.025165	21.5523	-0.033216	-79.8584
Var 2	-1.54035	-19.1412	0.0000024	10.2617
Var 3	-4.83E-05	-145.626	0.0001423	94.9006
A2	2.25003	17.7789	0.104239	2.31908
A3	7.76453	67.2447	0.419694	11.3146
A4	3.91854	32.8646	-0.000645	-0.014504
A5	7.55092	65.521	-0.127754	-2.77492
A6	3.40242	27.8368	(not selected)	
A7	6.8069	59.0602	-0.035453	-0.789192
A8	8.13567	70.7122	-0.044838	-0.962963
A9	2.08729	17.4963	(not selected)	
A10	4.2844	37.5928	-0.182436	-3.59657
A11	2.79837	24.3392	-0.035968	-0.800355
A12	(port not selected)			
A13	2.61132	20.6668	(not selected)	
A14	3.03977	23.2315	-0.03154	-0.702249
A15	1.69167	10.6211	(not selected)	
A16	3.83488	28.0154	(not selected)	
A17	3.721	26.6975	(not selected)	
A18	5.89248	37.2533	0.002592	0.058036
A19	3.58266	30.634	(normalized to zero)	
A20	2.11924	17.5206	(not selected)	
A21	2.96892	23.9614	(not selected)	
A22	0.781977	6.07576	(not selected)	
A23	1.88983	13.4179	(not selected)	
A24	(normalized to zero)		(not selected)	
LL at convergence: -243761			LL at convergence: -72487.8	

A1: Tokyo, A2:Niigata, A3:Yokohama, A4:Shimizu, A5:Nagoya, A6:Yokkaichi, A7:Osaka, A8:Kobe, A9:Shimonoseki, A10:K/Kyushu, A11:Hakata, A12:Tomakomai, A13:Hitachi, A14:F/Toyama, A15:Kanazawa, A16:Tsuruga, A17:Maizuru, A18:Sakai, A19:Hiroshima, A20:T/Kudamatsu, A21:Iwakuni, A22: Mitajiri, A23:Imabari, A24: Shibushi.

Table 3: Parameter Estimation-Malaysia

Port	Parameter Est.	t-stats
A1: Penang	1.93373	1.78713
Var 1: Bdist	-0.013493	-6.55319
Var 2: Btime	0.0012104	2.11800
Var 3: Bcost	0.0000781	4.43226
A2: Klang	0.271693	1.08256
A3: Kuantan	(normalized to zero)	
A4: Johor	1.97073	6.03979
A5: Singapore	0.547696	1.69903
Loglikelihood at convergence: -10623.4		

4.0 Optimal Containerized Liner Routing

Container vessel choice of calling ports is beyond the control of port authorities. In fact, it depends more on carriers and shippers and thus port authorities need to know also the carriers strategies for port planning purpose. This section provides containerized ocean liner routing formulation including that of feeder service.

4.1 Liner Routing Formulation

Formulated as two-objective integer optimization problem-carrier's cost and shipper's cost (Z_1, Z_2).

Minimize:

$$Z_1 = \sum_{v=F}\left\{f^M\left(C,U^v\right) + \sum_{p\in S^v} 2\left(G^P + \sum_{i=L} G^i\right)\left(H_p + T_p\right)\right\} \quad \text{.......(6)}$$

$$Z_2 = 2\left\{\sum_{k=K}\sum_{v=F} g^{kv} f^F\left(\sum_{i\in P}\sum_{j=P} y_{ij}^{kv}\right) + \sum_{p=S^v}\sum_{i=L_p} G^i T_p\right\} \quad \text{.........(7)}$$

Subject to:

$$\sum_{j\in Q} u_{ij}^v - \sum_{j\in N_i} u_{ji}^v = \begin{cases} 1 & (i = s, v\in F) \\ 0 & (i \neq s, i \neq t, v\in F) \\ -1 & (i = t, v\in F) \end{cases} \quad \text{................(8)}$$

$$\sum_{i\in Q}\sum_{j\in Q} u_{ij}^v \le |Q| - 1 \quad (s,t \notin Q, Q \subset P, |Q| \ge 2, v\in F) \text{.....(9)}$$

$$\sum_{j\in M_i} y_{ij}^{kv} - \sum_{j\in N_i} y_{ji}^{kv} = \begin{cases} \le 1 & (i = k, k\in K, v\in F) \\ = 0 & (i \neq k, i \notin S^v, k\in K, v\in F) \\ \ge -1 & (i = S^v, k\in K, v\in F) \end{cases} \text{..(10)}$$

$$\sum_{j\in M_k} y_{kj}^{kv} = \sum_{j=N_p} y_{jp}^{kv} \quad (k\in K, p\in S^v, v\in F) \text{.................(11)}$$

$$\sum_{v\in F}\sum_{j\in M_k} y_{kj}^{kv} \ge 1 \quad (k\in K) \text{...(12)}$$

$$U^v = \sum_{i\in P}\sum_{j\in P} h_{ij} u_{ij}^v \quad (v\in F) \text{...(13)}$$

$$\sum_{v\in F} g^{kv} = G^k \quad (k\in K) \text{...(14)}$$

$$\sum_{k\in K} g^{kv} \le C - \sum_{i\in S^v} G^i \quad (v\in F) \text{...(15)}$$

$$K = \left\{ i\in P \,\middle|\, \sum_{v\in F}\sum_{j\in N_i} u_{ij}^v = 0 \right\} \text{...(16)}$$

$$L_p = \left\{ k\in K \,\middle|\, y_{ip}^{kv} = 1, p\in S^v \right\} \quad (v\in F) \text{.........................(17)}$$

$$S^v = \left\{ k\in K \,\middle|\, \sum_{k\in K}\sum_{v\in F}\sum_{j\in N_i} y_{ji}^{kv} \ge 1, \sum_{v\in F}\sum_{j\in M_i} u_{ij}^v \ge 1 \right\} (v\in F) \text{..(18)}$$

$$S^v \subseteq HB \quad (v\in F); \quad g^{kv} \ge 0 \quad (k\in K, v\in F) \text{.......(19) \& (20)}$$

$$u_{ij}^v \in (0,1) \quad (all\ arcs(i,j), v\in F) \text{.............................(21)}$$

$$y_{ij}^{kv} \in (0,1) \quad (all\ arcs(i,j), k \in P, v \in F) \text{......................} (22)$$

Feeder route assignment can be solved by the following equations (transshipment problems[8]):

$$Minimize \quad \sum_{k \in K} \sum_{v \in F} c^{kv} g^{kv} \text{...} (23)$$

Subject to:

$$\sum_{v \in F} g^{kv} = G^k \qquad (k \in K) \text{...............................} (24)$$

$$\sum_{k \in K} g^{kv} \leq C - \sum_{i \in S^v} G^i \quad (v \in F) \text{.......................} (25)$$

$$c^{kv} = Min_{i \in S^v} \{B_i^* + T_i\} \text{...} (26)$$

$$Minimize \quad B_i = f^F \left(\sum_{i \in P} \sum_{j \in P} x_{ij} \right) \text{...............................} (27)$$

$$\sum_{j \in M_i} x_{ij} - \sum_{j \in N_i} x_{ij} = \begin{cases} 1 & (i = p, p \in S^v) \\ 0 & (i \neq s, i \neq k) \\ -1 & (i = k) \end{cases} \text{............} (28)$$

$$x_{ij} \in (0,1) \quad (all\ \ arcs(i,j)) \text{...................................} (29)$$

where,

C: ship capacity; Q: subset of P that is not empty
K: the set of local ports; P: the set of nodes
HB: the set of hub candidates; F: the set of ships
L_p: the subset of K such that ports are covered by feeders from hub p
M_i: the set of nodes being connected to node i by an actual arc (i,j)
Ni: the set of nodes being connected to node i by an actual arc (j, i)
S^v: the sets of hubs on the primary route of ship v
U^v: cruising time of the primary route of ship v
h_{ij}: transport time from nodes i to j
$f^M(\ )$: cost function of a ship;
$f^F(\ )$: tariff function of a feeder
H_p: handling cost per container at hub p
T_p: storage cost per container at hub p
G^i: the amount of containers of port i
s : the origin of primary routes
t : the destination of primary routes
u_{ij}^v : =1if a primary route connects by ship v nodes i to j, = 0 otherwise
y_{ij}^{nv} : =1 if a secondary route to local port k by ship v connects nodes i to j, = 0 otherwise

g^{kv} : amount of containers of local port k sent from/to a hub on a primary route of ship v
x_{ij} =1 if arc $(i - j)$ is selected for secondary route
B_i^* : optimal function value of equations (27)-(29)

5.2 Solution Procedure

The algorithm for the ship routing is given by **Fig. 6.** At present, the above contents are still under formulation and thus no results can be shown but it is highly anticipated that the primary and secondary routes can be identified related to port location, ship size, and cargo volume for present and future pattern. For Malaysia's case, since the major trading partners consist of ASEAN region and USA, the major ports in these regions are selected.

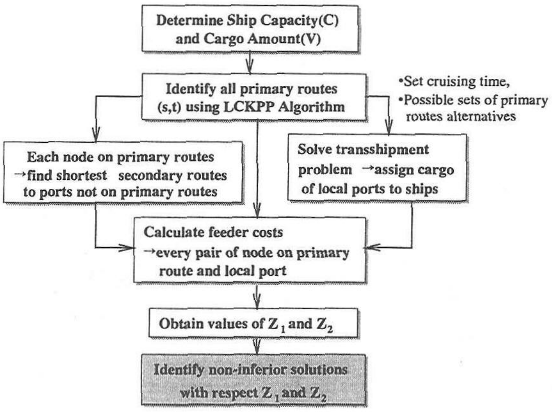

Fig. 6: Liner Routing Algorithm

5.0 SUMMARY

1. By performing the local port choice model, the following can be highlighted:
   i. probabilities of domestic port selection based on the selected variables can be determined.
   ii. Port hinterland can be demarcated and access facilities to ports can be prioritized.
2. Through containerized liner routing problem, routings formulation based on two objectives – minimization of carrier's cost and the cost by borne by shipper's associated with secondary feeder routes can be determined.
3. From 1) and 2), a more comprehensive Malaysia's port location planning can be proposed.

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