

A COMPARATIVE STUDY OF MODELS FOR PORT CHOICE

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Abstract: The purpose of this paper is to compare the fitness of several models for port choice. "Port choice" is an important issue in the present international trade container transportation market. In order to reduce the transportation costs, carriers have to choose a best port for calling. In the past, some researchers proposed some port choice models including the Stackelberg model, the equilibrium model and the fuzzy multiple criteria decision-making model. In this paper we will compare the fitness of each model for port choice, and then summarize the advantage and disadvantage of each model to be as a reference for future researchers.

Key Words: Containerization, Port choice, Stackelberg method, Equilibrium method, Fuzzy MCDM method.

1. INTRODUCTION

In the past, some models for port choice were been proposed. Chou et al. (2003a) discussed that three players can be considered in the container transportation market, port administrators, carriers, and domestic shippers. In this market, port administrators can be regarded as superior players, because they have complete information about the optimal behavior of both carriers and domestic shippers under given port management policies. Carriers, on the contrary, can be regarded as superior players to shippers, because carriers have complete information about the optimal behaviors of shippers under given carriers' services. This leads to a bi-Stackerberg problem. A Stackelberg model is proposed to simulate the flow of foreign trade container cargo using the mathematic programming. The model is used to explain the port choice of shipping companies and shippers.

Chou et al. (2003a) also proposed an Equilibrium model for port choice. That paper assumed that the international trade container transportation market could be regarded as an Equilibrium market. That is, both carriers and domestic shippers aim to maximize their revenues when they choose their ports. The Equilibrium model is formulated by the mathematic programming method.

Chou et al. (2003b) proposed a fuzzy multiple criteria decision-making model (FMCMDM) for port choice. The FMCMDM model was developed by the fuzzy multiple criteria decision-making method associated the mathematic programming. There are two solution process stages in the model. The first solution process is to compute each port's transportation demand split rate by fuzzy multiple criteria decision-making method (MCDM). In stage two, based on each port's transportation demand split rate, each port's transportation demand split is obtained by the mathematic programming.

The above-mentioned three models were tested by a case study of Taiwanese ports. This paper will introduce the case of Taiwanese ports as follows. There are three international container ports in Taiwan. They are Keelung port in North Taiwan, Taichung port in Central Taiwan and Kaohsiung port in South Taiwan respectively. Every year almost 50% (3,085,533 TEUs) of total export and import container volume in Taiwan area is from/to North Taiwan area, 20% (1,234,215 TEUs) is from/to Central Taiwan area and 30% (1,851,320 TEUs) is from/to South

Taiwan area respectively. Because Kaohsiung port has lower container handling charges, higher operation efficiency and higher frequency of ship calls than those of Keelung port and Taichung port. As a result, in 2000 the container throughput split for Keelung port, Taichung port and Kaohsiung port are 30% (1,859,677 TEUs), 15% (851,171 TEUs) and 55% (3,460,219 TEUs) respectively. That is, almost 1,200,000 TEUs exported/imported containers of North Taiwan area have to be shipped via Kaohsiung port in South Taiwan every year.

The rest of this paper is organized as follows. In Section 2 this paper first present the Stackelberg model for port choice. The Equilibrium model for port choice is proposed in Section 3. In Section 4 the fuzzy multiple criteria decision-making model for port choice is shown. Finally, the comparison results of these three models for port choice are given.

2. THE STACKERLBERG MODEL FOR PORT CHOICE

In the past, Yang (1995, 1996, 1998, 1999) assumed that the international trade container transportation market could be regarded as a Stackelberg market. That is, three players including port administrators, carriers and domestic shippers, can be considered in the international container transportation market. Port administrators can be regarded as the superior players, because they have complete information about the optimal behavior of both carriers and domestic shippers under a given port management policy. Carriers, on the contrary, can be regarded as superiors and leaders to domestic shippers who are followers in the market, because carriers have complete information about the optimal behavior of shippers under given carriers' services. This leads to a bi-level Stackelberg problem. The relationship between port administrators, carriers, and shippers is shown in Figure 1.

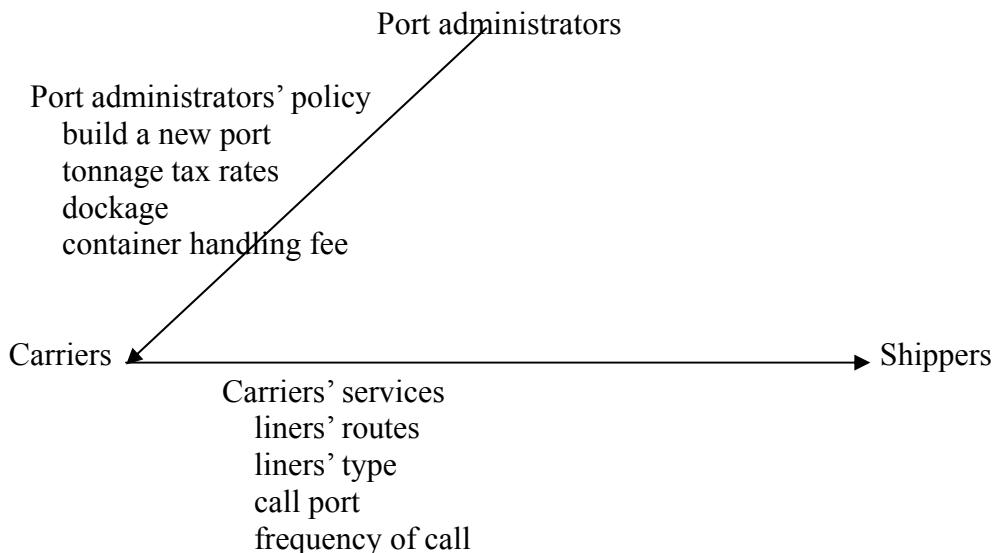


Figure 1. Relation Between Port administrators, Carriers and Shippers in Stackelberg Model

In the Stackelberg model for port choice, the carrier aims to maximize his net revenue by using his strategies of routing, vessel type, call port and frequency of call on each route. While making these strategies, the carriers should take into account all information concerning the behaviors of shippers. For example, carriers first investigate the origin destination (O-D) of foreign trade containers, then make an estimation of flows of containers, and finally decide the services and declare it. So carriers have complete information about domestic shippers. For this reason carriers can be regarded as leaders and domestic shippers can be regarded as followers in the foreign trade container transportation market.

Domestic shippers may choose their port to minimize the total transportation cost under a given liner service. They also consider the port access time. However, the port access time is often neglected when modeling.

According to the above analysis, we can construct the structure of the Stackelberg model for port choice in Figure 2.

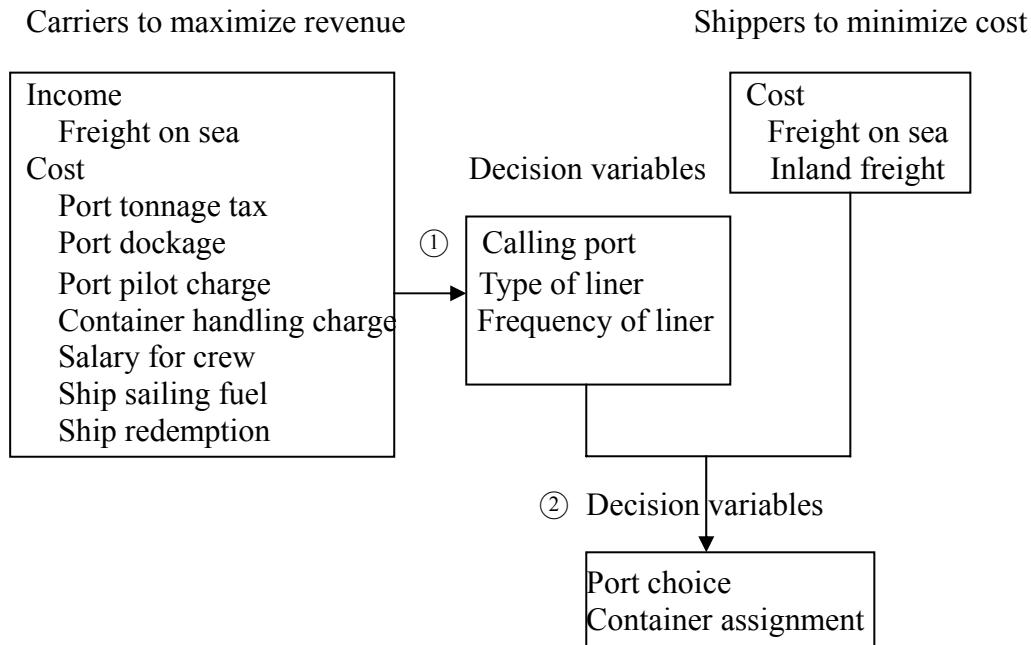


Figure 2. Structure of Stackelberg Model for Port Choice

In the formulation of the behaviors of carriers and domestic shippers, the following are premised and assumed.

- Only foreign trade container cargo is considered.
- O-D zones of foreign trade containers are denoted by k and k' , respectively.
- Only the Taiwan-America route is considered. It is assumed that Taiwan area has two major international trade ports. They are the Kaohsiung port and Keelung port, respectively. L.A. port is the only port in America area. A port is denoted by i, j , where i is the departure port, and j is the destination port.
- Every berth at any port is available.
- The total container berth capacity of each country must be greater than the necessary number to handle total volume of exported and imported containers.
- Competition between shipping companies is not taken into account, i.e. a single carrier is assumed.
- The carrier aims to maximize his net revenue.
- The total capacity of container ships assigned to a specific route is at least as great as the total container transportation demand for the route. That is, all foreign trade containers per unit period must be transported in that period.
- Shippers aim to minimizing their cost when choosing their port, which include the freight on sea and port access cost.
- Port access time is neglected.
- Only inland container transportation for domestic shippers in Taiwan area is considered. Thus, overseas shippers' behaviors are neglected.

As previously mentioned, carriers aim to maximize their net revenues. The carriers' net revenues equal the total freight minus the total cost. Thus the carriers' objective function is formulated in equation (1) and constraints are formulated in equations (10)-(12).

$$\text{Max RS} = \text{RF} - (\text{CT} + \text{CP} + \text{CL} + \text{CB}) - (\text{CC} + \text{CF} + \text{CD}) \quad (1)$$

RS: carriers' net revenue,
 RF: total volume of freight on sea,
 CT: port tonnage tax,
 CP: port pilot charge,
 CL: container handling charge,
 CB: port dockage charge,
 CC: salary for crew cost,
 CF: ship sailing fuel cost,
 CD: ship redemption cost.

$$RF = \sum_L \sum_i \sum_j R_{ij} (\lambda_{ij}^L S^L Y_{ij}^L) \quad (2)$$

i : departure port, $i=1, 2, \dots, I$.

j : destination port, $j=1, 2, \dots, J$.

R_{ij} : container freight from port i to port j (USD/TEU).

λ_{ij}^L : load factor of vessels of type L between port i and port j .

S^L : loading capacity of vessels of type L .

Y_{ij}^L : decision variable, the number of vessels of type L sailing between port i and port j .

$$CT = \sum_L \sum_i \sum_j W^L (C_{ti} + C_{tj}) Y_{ij}^L \quad (3)$$

W^L : gross tonnage of vessels of type L .

C_{ti} : port tonnage tax at port i (USD/gross ton).

C_{tj} : port tonnage tax at port j (USD/gross ton).

$$CP = \sum_L \sum_i \sum_j W^L (C_{pi} + C_{pj}) Y_{ij}^L \quad (4)$$

C_{pi} : port pilot charge at port i (USD/gross ton).

C_{pj} : port pilot charge at port j (USD/gross ton).

$$CL = \sum_L \sum_i \sum_j (C_{li} + C_{lj}) \lambda_{ij}^L S^L Y_{ij}^L \quad (5)$$

C_{li} : container handling charge at port i (USD/TEU).

C_{lj} : container handling charge at port j (USD/TEU).

$$CB = \sum_L \sum_i \sum_j (T_{bi}^L C_{bi}^L + T_{bj}^L C_{bj}^L) Y_{ij}^L \quad (6)$$

T_{bi}^L : mooring time of vessels of type L at port i .

T_{bj}^L : mooring time of vessels of type L at port j .

C_{bi}^L : port dockage charge for vessels of type L at port i .(USD/hour)

C_{bj}^L : port dockage charge for vessels of type L at port j .(USD/hour)

$$CC = \sum_L \sum_i \sum_j C_c^L T_{ij}^L Y_{ij}^L / 365 \quad (7)$$

C_c^L : the annual crew salary per vessel of type L (USD/vessel/year).

T_{ij}^L : the cycle time of a vessel of type L routing between port i and port j .

$$CD = \sum_L \sum_i \sum_j C_d^L T_{ij}^L Y_{ij}^L / 365 \quad (8)$$

C_d^L : the annual ship redemption cost of a vessel of type L .

$$CF = \sum_L \sum_i \sum_j C_F^L T_{Sij}^L Y_{ij}^L / 330 \quad (9)$$

T_{Sij}^L : the sailing days of a vessel of type L from port i to port j .

C_F^L : the annual sailing fuel cost of a vessel of type L .

Subject to

$$Y_{ij}^L \geq 0, \quad \forall i, j, L \quad (10)$$

$$\sum_i \sum_j Y_{ij}^L = Y^L \quad (11)$$

$$\sum_L \sum_i \sum_j \lambda_{ij}^L S^L Y_{ij}^L = Q \quad (12)$$

Equation (10) means that the decision variable Y_{ij}^L is a positive number. Equation (11) means that the total number of vessels of type L assigned to sail between port i and port j equals to the number of vessels of type L presented by carriers, where Y^L is the number of vessels of type L presented by carriers. Equation (12) shows that the total capacity of vessels presented by carriers equals to the total volume of foreign trade container in all origin zones, where Q means the total volume of foreign trade container in all origin zones.

Domestic shippers aim to minimize their freight costs under a given marine transportation service presented by carriers. In order to achieve this, shippers must choose carefully their ports. The shippers' freight costs consist of the freight on sea and the inland transportation cost. Thus the shippers' objective function is formulated in equation (13) and constraints are formulated in equations (15)-(18).

$$\text{Min CO} = \text{RF} + \text{CI} \quad (13)$$

CO: total transportation cost of shippers,

RF: freight on sea,

CI: inland transportation cost.

$$CI = \sum_k \sum_i \sum_j \sum_{k'} (C_{Iki} + C_{Ijk'}) X_{kijk'} \quad (14)$$

k : origin zone of foreign trade container, $k=1, 2, \dots, K$.

k' : destination zone of foreign trade container, $k'=1, 2, \dots, K'$.

C_{Iki} : inland transportation cost from k to port i .

$C_{Ijk'}$: inland transportation cost from port j to k' .

$X_{kijk'}$: decision variable, the volume of foreign trade container assigned by shippers, whose origin zone is k , departure port is port i , discharge port is port j , and destination zone is k' .

Subject to

$$X_{kijk'} \geq 0, \quad \forall k, i, j, k' \quad (15)$$

$$\sum_k \sum_i \sum_j \sum_{k'} X_{kijk'} = Q \quad (16)$$

$$\sum_k \sum_j \sum_{k'} X_{kijk'} = \sum_L \sum_j \lambda_i^L S^L Y_{ij}^L \quad (17)$$

$$\sum_{k'} \sum_i \sum_j X_{kijk'} = Q_k \quad (18)$$

Equation (15) ensures that decision variable $X_{kijk'}$ is a positive number. Equation (16) means that the total volume of foreign trade containers assigned by shippers equals to the volume of foreign trade containers in all origin zones. Equation (17) guarantees that the volume of foreign trade containers which departed from port i assigned by shippers equals to the capacity of vessels calling port i assigned by carriers. Equation (18) means that the total volume of foreign trade containers assigned by shippers in origin zone k equals to the volume of foreign trade containers in origin zone k , where Q_k is the volume of foreign trade containers in origin zone k .

3. THE EQUILIBRIUM MODEL FOR PORT CHOICE

In the past, Chang (1974), Zong (1978), Wan (1980) and Gleave (1981) assumed that the international trade container transportation market could be regarded as an Equilibrium market. That is, both carriers and domestic shippers aim to maximize their revenues when they choose their ports. Figure 3 shows the structure of the Equilibrium model for port choice. According to the structure, the objective function of Equilibrium model is formulated in equation (19) and constraints are the same as the constraints in the Satckerlberg model for port choice.

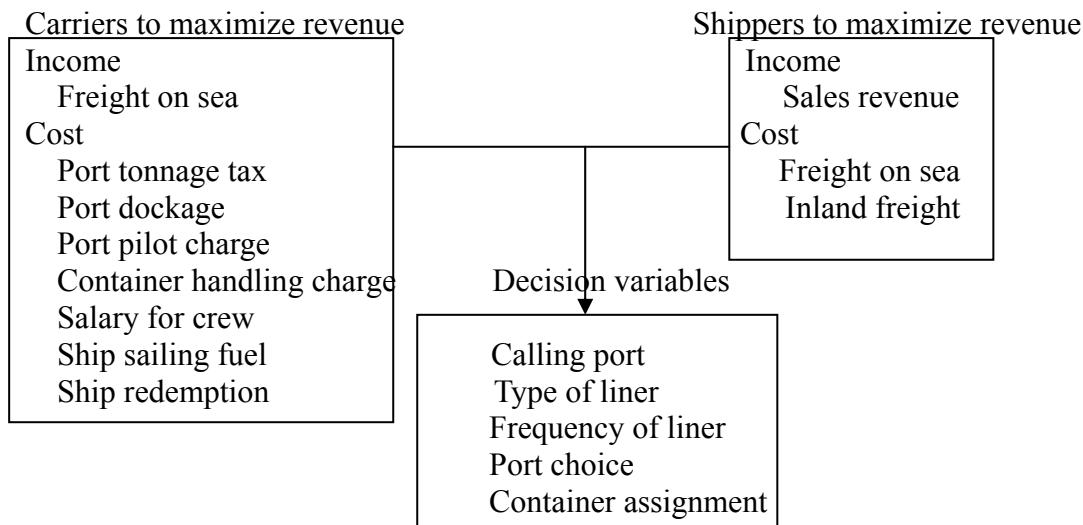


Figure 3. The Structure of Equilibrium Model for Port Choice

$$\text{Max RS+RO}=(RF-CT-CP-CL-CB-CC-CD-CF)+(LC-RF-CI) \quad (19)$$

RS: net revenue of carriers

RO: net revenue of shippers

LC: sales revenue of shippers

4. FUZZY MCDM MODEL FOR PORT CHOICE

The concept of linguistic variable is very useful to describe the human judgments or preference in many situations. Terms of linguistic variables could be called “very poor”, “poor”, “medium poor”, “medium”, “medium good”, “good”, “very good”, and so on. These linguistic variables can be also expressed in fuzzy numbers. Owing to the fuzziness of the container port selection problem, the importance weight of various criteria and the preference of each container port are considered as linguistic variables in the paper. These linguistic variables can be expressed in trapezoidal fuzzy numbers. The membership functions of linguistic variables are from the shipping company. The authors interviewed the shipping company and obtained the subject membership functions of linguistic variables. Then the author interviewed 4 shipping companies in Taiwan. The important weight of each criteria and the preference of each container port are obtained and shown.

The solution procedure is shown as follows. Assume there are m shipping companies (S_1, S_2, \dots, S_m), n container ports (A_1, A_2, \dots, A_n), i evaluation criteria (C_1, C_2, \dots, C_i) and j sub-criteria (SC_1, SC_2, \dots, SC_j). Let $P_{(m, An, Ci, SCj)}$ be the m^{th} shipping company's fuzzy preference assigned to the n^{th} container port under criteria C_i and sub-criteria SC_j . W_{mi} and W_{mj} are the m^{th} shipping company's importance weights for C_i and SC_j , respectively. Let $P_{mnij} = W_{mi} \otimes W_{mj} \otimes P_{(m, An, Ci, SCj)}$. And let $TP_{mn} = \sum_{j=1}^J \sum_{i=1}^I P_{mnij}$ be the m^{th} shipping company's total fuzzy preference for the n^{th} container port. $R_{mn} = TP_{mn} / \sum_{n=1}^N TP_{mn}$ be the m^{th} shipping company's transportation demand split rate for the n^{th} container port. $R_n = \sum_{m=1}^M Q_m R_{mn} / \sum_{m=1}^M \sum_{n=1}^N Q_m R_{mn}$ be all shipping companies' transportation demand split rate for the n^{th} container port. Q_m is the m^{th} shipping company's market share in Taiwan area.

Then the authors develop a port choice model by the mathematic programming. Domestic shippers aim to minimize their freight costs under a given marine transportation service presented by carriers, i.e. the transportation demand split rate. The shippers' freight costs consist of the freight on sea and the inland transportation cost. Thus the shippers' objective function is formulated in equation (20) and constraints are formulated in equations (21)-(25).

$$\text{Min } \text{TC} = \text{FR} + \text{CI} \quad (20)$$

TC: total transportation cost of shippers,

FR: freight on sea,

CI: inland transportation cost.

$$\text{CI} = \sum_k \sum_i \sum_j \sum_{k'} (CI_{ki} + CI_{jk'}) X_{kijk'} \quad (21)$$

k : origin zone of foreign trade container, $k=1, 2, \dots, K$,

k' : destination zone of foreign trade container, $k'=1, 2, \dots, K'$,

CI_{ki} : inland transportation cost from k to port i ,

$CI_{jk'}$: inland transportation cost from port j to k' ,

$X_{kijk'}$: decision variable, the volume of foreign trade containers assigned by shippers, origin zone is k , departure port is port i , discharge port is port j , and destination zone is k' .

Subject to

$$\sum_{k'} \sum_i \sum_j X_{kijk'} = Q \quad (22)$$

$$\sum_k \sum_j \sum_{k'} X_{kijk'} = R_i Q \quad (23)$$

$$\sum_{k'} \sum_i \sum_j X_{kijk'} = Q_k \quad (24)$$

$$X_{kijk'} \geq 0, \quad \forall k, i, j, k' \quad (25)$$

Equation (22) means that the total volume of foreign trade containers assigned by shippers equals to the volume of foreign trade containers in Taiwan area per year. Q is the total volume of foreign trade containers in Taiwan area per year. Equation (23) ensures that the volume of foreign trade containers shipped from port i assigned by shippers equals to the capacity of vessels calling port i assigned by carriers. R_i is the transportation demand split rate for port i . Equation (24) means that the total volume of assigned containers from origin zone k equals to the volume of foreign trade containers in origin zone k , where Q_k is the volume of foreign trade containers in origin zone k . Equation (25) decision variable $X_{kijk'}$ is a positive number.

5.COMPARISON AND CONCLUSION

The Stackelberg model, the Equilibrium model and the fuzzy MCDM model are tested by a Taiwanese case. The results for the Stackelberg model, the Equilibrium model and the fuzzy MCDM model are shown in Table 1.

Table 1. Results for These Three Models for Port Choice (TEUs)				
Ports Models	Keelung port	Taichung port	Kaohsiung port	Total
Actual Volume	1,859,677	851,171	3,460,219	6,171,067
Stackelberg Model	0 (-1,859,677) (-100%)	---	5,400,000 (+1,939,781) (+56%)	5,400,000
Equilibrium Model	3,000,000 (+1,140,323) (+61%)	---	2,400,000 (-1,060,219) (-30%)	5,400,000
Fuzzy MCDM Model	1,900,688 (+41,011) (+2%)	1,487,227 (+636056) (+74%)	2,783,153 (-677,066) (-19%)	6,171,068

(): error

This paper compares three models for port choice, including the Stackelberg model, the Equilibrium model and the fuzzy MCDM model. The results show that these three models cannot be used to explain the actual port choices of carriers and shippers well. Thus we will develop a better model for port choice in the future research.

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