Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 2483 - 2493, 2005

EVALUATION OF COMPETITION ABILITY AND MARKET SHARE FOR CONTAINER PORT

Yang Yanbing
Associate Professor
Dalian Maritime University
1 Linghai Road, Ganjingzi, Dalian
116026, China
Fax: +81-11-706-6864
E-mail: isc-sec@eng.hokudai.ac.jp

Yang Zhongzhen
Professor
Dalian Maritime University
1 Linghai Road, Ganjingzi, Dalian
116026, China
Fax: +86-411-8472-6756
E-mail: yangzhongzhen@263.net

Yang Zan
Professor
Dalian Maritime University
1 Linghai Road, Ganjingzi, Dalian
116026, China Fax: +81-11-706-6864
E-mail: isc-sec@eng.hokudai.ac.jp

Zuo Zhi
Master Course Student
Dalian University of Technology
2 Linggong Road, Ganjingzi, Dalian
116024, China
E-mail: zuozhiukk@yahoo.com.cn

Abstract: This study aims to develop an index system to evaluate container port competition ability, and to provide theoretical foundation for regional ports' integration. First we summarize the actual method for evaluating container port performance. Through a series of surveys on ports, clients, and forwarders as well as the logistics experts, we analyze and sort the factors affecting the container port competition ability. Basically, they are port scale, operation condition, facility condition, service level, and management system. Second, experienced shipping and port experts are chosen to score the factors, and with the survey results we determine weights of factors in each layer respectively. Then analytical hierarchy process (AHP) is applied to quantify the index system and work out the comprehensive score of each port. At last, based on this index system and the optimal path-searching algorithm we figure out each port's hinterland in the Bohai sea region in China.

Keywords: Container Port, Evaluation Index System, AHP, and Hinterland.

1. BACKGROUND

Due to the continual economic growth, China's container ports and container transportation has developed rapidly. In 1992 no container port in China's mainland has capacity over one million TEU, while in 2002 there are 8 container ports whose capacity is over one million TEU. Now capacity of these ports continues to increase and China has become a big country in terms of container transportation. According to "Chinese Statistic Year Book 2003", by the end of 2002 there are 83 container berths with capacity over ten thousand tons, and the total dealt containers are about 37.2 million TEU. It can be said that the rapid increment of container port will continue for many years, it means that China's container transportation will develop further in the near future. Because of the development of economy and trade, the role of port, which is the node of water transportation and international logistic, becomes more and more important. As the reform happened on port management system in China, more and more cities relate the development of ports with their urban and regional development. Many local governments are planning to develop ports in order to obtain the effects of port scale economy and further to prompt the development of the hinterland. The strategy of developing city with port construction and driving urban economy with port industry is widely accepted in China. For example, Dalian is planning to raise its international status and drive its development and prosperous through construction of northern-eastern Asia shipping center. Strategy of development of port in cities and regions induces port building boom and enforcement of the ports. For example, capacity of big four ports around Baihai bay will reach 10 million TEU respectively, and all of them are planning to become northern shipping center. It can be seen that strategy and objective of ports of Dalian, Tingdao and Tianjin are almost same.

Similar strategy of ports in the same region results in intense competition. Although, surplus supply may optimize container transportation pattern, and improve service level of the port and transportation efficiency, it may also induce resource wastes and pernicious competition, which will result in unreasonable transportation route and chaos of transportation market. To avoid the negative impact, it is necessary to have a guideline to direct the port planning and designing in a region. This guideline should maximize total social benefit, analyzes the spatial and temporal distributions of relationship between container transportation demand and supply and optimize the distribution and sizes of container ports in a region. This is a problem of facility network design and planning. Many modeling approaches have been applied to facility network design problems, most of which fall under the rubric of location allocation models. Location allocation models provide a framework for determining the best location for different types of facilities based on allocation of consumers to them. The most widely known are the *p*-median, covering and plant location models (Birkin, 2002). Most subsequent work on facility network optimization draws from the application and extension of this classical location allocation framework. The basic *p*-median problem is to find the optimum locations for *p* facilities relative to *q* demand zones. However, for port planning there are two major draw-backs with these traditional "proximal-area" based spatial optimization models. The first is that in reality travel distance is not the only factor affecting harbor choice. The second is that they take no notice of competition. This may not be a problem in public facility or monopolistic market location problems, but in the competitive conditions, the performance of a harbor's network heavily depends on the location of that network in relation to those of its competitors. Correspondingly, a great deal of work has been devoted to extending these models to represent consumer behavior and the competitive nature of the harbor environment more naturedly.

To represent customer behavior in facility network design problems, these traditional methods have been extended by embedding problistic choice models. Behavioral patterns are estimated relative to a number of factors in addition to distance. Prominent examples of these alternatives include the "*p*-choice model" (Hodgson, 1978; Ghosh and Harche, 1993), the Multiplicative Competitive Interaction model (Nakanishi and Cooper, 1974; Achabal *et al*., 1982; Ghosh and Craig, 1991). An alternative approach is to use a logit model to represent customer behavior and estimate market share. Recent advances in this aspect of optimization modeling have occurred as result of parallel development in customer modeling techniques. These techniques have developed considerably over the last two decades (Fotheringham, 1983; Yano, 1993; Clarke *et al.,* 1997). To present the competitive nature of facilities, a vast of literature has developed on competitive facility location models. Such models are defined as those in which systems of facilities compete to attract customers, and a firm's market share depends on the location of its facilities relative to those of competitors (Ghosh and Harche, 1993).

The core of these studies is the development of utility function for user choice decision, and then choice probability of each facility is calculated based on stochastic choice theory, and then users attracted by a facility can be calculated. The projected scenarios can be evaluated through the above calculation and optimal facility distribution can be found under market mechanism. Based on this principle, Fujino (Fujino *et al*, 1995) developed a probalistic model, which can analyze behavior of container shipping company chooses port. It further analyzed interaction between shipper and shipping company. Takase (Takase *et al*, 1996) developed a demand and supply model concerning international air passenger who use different routes or different flights based on game theory, and then he put forth a methodology to calculate optimal flights and users of an airport and with equilibrium method. Noguchi (Noguchi *et al*, 2000) thought that international travelers tended to choose airport with more flights and this trend is limited by the distance between origin and destination in some degree. He reflected the behavior of airline companies and travelers in the behavior of selecting airport, to simulate the attractiveness of airlines and travelers subject to a certain generation and attraction transportation volumes. Su *et al*. (2003) established a comprehensive performance measuring system with the Balanced Scorecard and developed a 31 performance measuring criteria. They demonstrated how this measuring system is used for ports performance comparison through the methodologies of AHP and fuzzy set theory. Chou *et al* (2003) proposed a transportation demand split model for international container ports in Taiwan area. They first computed each port's transportation demand split rate by fuzzy multiple criteria decision-making method, and then based on each port's transportation demand split rate to obtain each port's transportation demand split by mathematic programming. Yang Zan (1999) discussed port management policy in an equilibrium shipping market. Models are proposed to simulate the flow of foreign trade container cargo using game theory and mathematic programming. These models are used to explain the interaction of port management policy, shipping companies and shippers.

Based on existing literatures, this study aims to 1) establish a index system and evaluation model for container port market share analysis; 2) calculate probability of a city choosing a port based on *p*-choice model in a region covered by a container port network, and further partition hinterland for nodes in the network with the choice probability and container volume. Evaluating model for container port market share is developed with AHP, the output of model is the relative utility of a user selecting a port. As mentioned before, a user selecting behavior is also affected by the time, cost, and reliability of the land transportation to the port. Here transportation impedance between city and port is analyzed in a super network of railways and road networks. Then Logit model is used to calculate the probability of users in a city selecting a port in the context of marketing mechanism, and the scale of hinterland of a port in the region. All of the results will give a theoretical support for integrating and optimizing the container port network in a region.

2. FACTORS AFFECTING MARKETING ABILITY OF CONTAINER PORT

In transportation market, competition ability of port relies on its service level, the better the service level the stronger the ability and the more the attracted users. Based on our experience and survey results on ports, users, forwarders, and shipping companies, we analyze the factors affecting competition ability of container port as follows.

1) Port Scale

They are factors concerning ship-holding capacity, handled container quantity, natural condition (such as location, water and climate conditions), size and hard and soft environment of the city. Factors affecting the soft environment include globalization level, freetlization level, and service levels of the regional monitorial, insurance, commercial and logistic industries.

2) Operation Condition

They are factors directly related to transportation between port and users, port and shipping company, such as frequency of container ships and shipping route density, condition of collecting and distributing system, and comprehensive operating cost. Since frequency of container ships and shipping route density determine the transportation speed and time of container to the destination, collecting and distributing conditions affect convenience and speedy of container freight to and from the port.

3) Facility Condition

It is an integrated index to reflect the port infrastructure level, berth capacity, size of the container yard in the port, storage capacity, equipments for loading and unloading, and efficiency of the equipment are included.

4) Service Quality

They are entrance delay, average stay time in the port, information service level. Because they influence the efficiency of shipping company, and users especially shipping company takes them seriously.

5) Management Level

This means that if the EDI system, safety monitoring system, information management system and GPS navigation guiding system are available.

3. INDEX EVALUATING SYSTEM AND ITS QUANTIFYING METHOD

Based on above analyses, factors affecting competition ability of container port can be classified into five categories, and each category can be further divided into several sub-categories, then an AHP index system to evaluate container port competition ability can be established according to the hierarchy and relationship of the factors as follows.

3.1 Evaluation Model for Port Competition Ability

Setting $X = \{x_1, x_2, x_3, x_4, x_5\}$ as a vector of factors affecting port marketing ability, where $x_i = \sum_j \alpha_{ij} x_{ij}$, x_{ij} =sub-factors of j in factor i ($i = 1,...,5$), α_{ij} =weight of sub-factors of j in factor i , $\{x_{ij}\}$ is as follows.

$\{x_{11}, x_{12}, x_{13}\} =$ {Ship-holding capacity, Handled containers, Natural condition}

$\{x_{21}, x_{22}, x_{23}\} =$ {Frequency of container ships and shipping route density, generalized cost, International trade transportation function}

$\{x_{31}, x_{32}, x_{33}, x_{34}, x_{35}\} =$ {Berth capacity, Storage capacity, Equipments for loading and unloading, Container yard size, Efficiency of the equipment}

$\{x_{41}, x_{42}, x_{43}\} =$ {Entrance delay, Average staying time, Information service level}

$\{x_{51}, x_{52}, x_{53}, x_{54}\} =$ {EDI system, Safety monitoring system, Information management system, GPS navigation guiding system}

Therefore, marketing ability of a container port can be depicted with formula (1), where $\beta_i, (i = 1,...,5)$ are the weights of factors of the five categories.

$$M = |\beta X| = \sum_{i=1}^{5} \beta_i \sum_j \alpha_{ij} x_{ij} \qquad (1)$$

Accuracy of the calculated M depends on the method and correctness of determining the weights β, α . If β, α are determined rationally M will be correct and fit the fact, vice-visa. Then the key problem in the model is to develop a method to rationally estimate β, α . Moreover, it can be seen that there are many descriptive factors in $\{x_{ij}\}$, then in addition to develop a weight determining method, it is also necessary to have a method to quantify these descriptive factors. Here AHP is used to deal with both of them.

3.2 Quantifying with AHP

1) Structure of AHP in this study

AHP is developed by T.L. Satty in the end of 1970s, its basic idea is to divide a complicated problem into sub-factors and group them into several layers according to the dominating relationship to construct a hierarchy structure (Yang, 2002). And then importance of factors in a layer is determined through pair comparison. After order of factors in a layer and order of layers in the system are determined, all weights of factors to the decision layer can be calculated. The merit of AHP is that it can determine the importance of factors in decision maker's consciousness through questionnaire, and then to quantify the consciousness. AHP structure in this study is illustrated with Fig.1, on the top of the frame there is the goal layer *A*, and then comes two criteria layers C_1 and C_2, at the bottom of the frame there are the being evaluated ports.

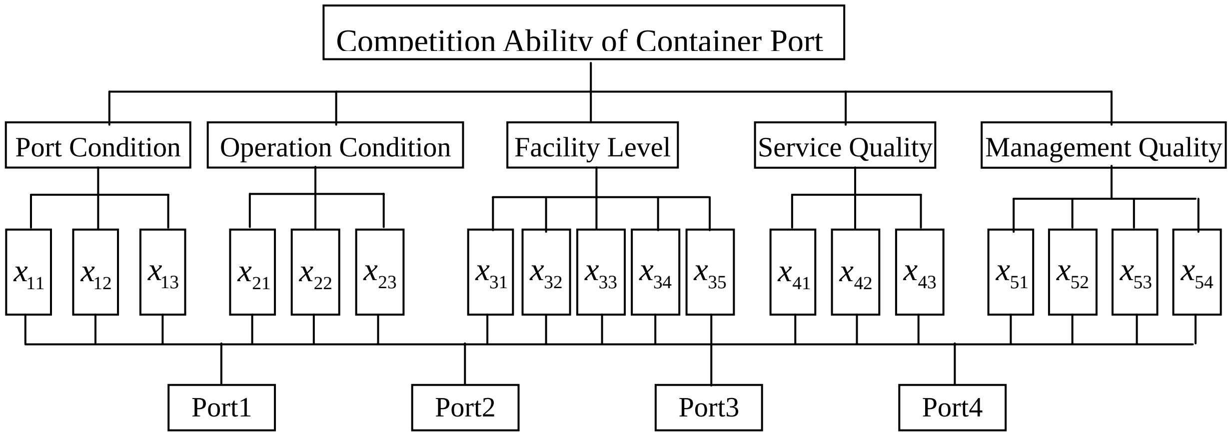

Fig. 1 AHP Frame for Evaluating Competition Ability of Container Port

2) Questionnaire, Judge Matrix and Weight Vector

In AHP, first we have to get judgment matrixes in the layers through questionnaire survey, to calculate weight vectors of the matrixes with eigenvalue method, and to carry out the identical test. Second, weight vectors of judgment matrixes is calculated with weight vector integration method under the condition of single criteria for plural decision makers and the integrated weight vectors can be obtained. It is found that exclusive of the integrated judgment matrix got lost, therefore, systematic errors tend to be produced. In order to avoid the errors, questionnaire designed for this study combines the merits of fuzzy judgment and AHP. First values of indices relationships in each layer in the framework are given based on fuzzy judgment questionnaire, and then judgment matrix of AHP is given based on the comparison table. For example, two questionnaires for five indices in second layer are designed and distributed in two times. In first round, 17 questionnaires are distributed and 15 useful questionnaires were reclaimed and after statistical calculation, the arithmetic averages are as Table 1 shows.

Table 1 Weights in the first Layer

Factors	Port Condition	Operation Condition	Equipment Condition	Service Level	Management Level
Weight	0.22	0.21	0.18	0.24	0.15

In second round, in order to o obtain the judgment matrix of AHP based on Table 1 and the weight ratio matrix of the indices, 15 copies of questionnaire sheets are distributed and 12 of them are reclaimed. Among them 83.3% experts agreed with Table 2, another two agreed principally. It means that AHP judgment matrix based on weight ratio matrix is accepted by the experts. Based on suggestions of the experts and requirement of the identical test, this study slightly adjusted the results. The regular for the adjustment is that if the difference between weight ratio and standard value in Table2 is bigger than 0.02, add ± 1 to the adjusted value to satisfy the requirement of identical test. Here 9-rank important degree put forth by T.L.Saaty is used, it means that “same important”=1, “a little more important”=3, “more important”=5, “much more important”=7, “seriously more important”=9, “a little less important”=1/3, “less important”=1/5, “much less important”=1/7, “seriously less important”=1/9, while 2, 4, 6, 8 represent the middle values between 1, 3, 5, 7, 9. As the result, Table 3 is obtained, which satisfies identical test and is a 5×5 judgment matrix of second layer to objective layer.

Table 2 Table Corresponding to AHP Method

Value of AHP	1	2	3	4	5	6	7	8	9
Weigh Ratio	0.95-1.05	1.05-1.15	1.15-1.25	1.25-1.35	1.35-1.45	1.45-1.55	1.55-1.65	1.65-1.75	1.75-1.85

Table 3 Relative Importance of Five Factors in Port Competitive Ability

	Port Environment	Operating Condition	Equipment Condition	Service Level	Management Level
Port Environment	1	1	3	1/2	5
Operating Condition	1	1	3	1/3	5
Equipment Condition	1/3	1/3	1	1/5	3
Service Level	2	3	5	1	7
Management Level	1/5	1/5	1/3	1/7	1
Eigenvalue *(RSW)*	0.230	0.227	0.107	0.395	0.041

Eigenvalue (*RSW*) in Table 3 means the weight vector of factor layer C_1 to objective layer A. Here vector of Eigenvalue (*RSW*) is {a_1, a_2, a_3, a_4, a_5}={0.230, 0.227, 0.107, 0.395, 0.041}. Repeating above process, weight vector of factor layer C_2 to factor layer C_1 can be calculated as Tables 4, 5, 6, 7, and 8.

Table 4 Urban Environment

	x_{11}	x_{12}	x_{13}
x_{11}	1	1/2	2
x_{12}	2	1	3
x_{13}	1/2	1/3	1
W_1	0.309	0.529	0.162

Table 5 Operating Condition

	x_{21}	x_{22}	x_{23}
x_{21}	1	3	3
x_{22}	1/3	1	1
x_{23}	1/3	1	1
W_2	0.600	0.200	0.200

Table 6 Facility Condition

	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}
x_{31}	1	1	1	2	1/9
x_{32}	1	1	1	2	1/9
x_{33}	1	1	1	2	1/9
x_{34}	1/2	1/2	1/2	1	1/9
x_{35}	9	9	9	9	1
W_3	0.093	0.093	0.093	0.048	0.673

Table 7 Service Quality

	x_{41}	x_{42}	x_{43}
x_{41}	1	1/2	7
x_{42}	2	1	9
x_{43}	1/7	1/9	1
w_4	0.391	0.551	0.058

Table 8 Management Quality

	x_{51}	x_{52}	x_{53}	x_{54}
x_{51}	1	2	3	2
x_{52}	1/2	1	3	2
x_{53}	1/3	1/3	1	1/3
x_{54}	1/2	1/2	3	1
w_5	0.372	0.302	0.093	0.233

With AHP method we obtained the weight coefficients, which appear in formula (1), in fact RSW in Table 3 equals to β and w_i in Tables 4-8 equals to α_i. If a port is given for evaluation and its attributes such as port environment, operating condition are known, value of M can be calculated with formula (1). This calculation method will be illustrated at the section of numerical test. In next section method of quantifying descriptive factors is introduced.

3.3 Quantification of Descriptive Port Factors

In the evaluation system, some factors are descriptive rather than quantified ones, for example, availabilities of EDI system, safety monitoring system or GPS navigation guiding system are not quantified factors. Many existing studies have used 0-1 variable to represent with-without situations, and then effects of with-without situations are analyzed with regressive method. Since factors in lower layer will seriously affect factors in upper layer, 0-1 variables may not be able to indicate the numerical difference of with or without a kind of condition exactly. Here scores marked by users are used to represent the differences. It also uses the evaluation principle of AHP for quantifying descriptive factors to ask users to mark the importance for a kind of condition. For example, surveyed users are asked to mark the degree of importance of a port with EDI as “unimportant, important, very important”, and the scores for the degree are 0, 2, and 4.

4. CALCULATION OF DYNAMIC HINTERLAND

It can be said that competition capacity means the accept degree of a user for a container port, or generalized service level of a container port for a user. It is not the only factor to affect user’s port choice. Port choice behavior will abide by maximum utility principle, namely the choice will maximize his utility. Due to the errors of subjective judgment and objective sensing the choice is stochastic. It means that users do not always choose the alternative with the biggest utility, but alternatives with bigger utilities will be chosen more. The mathematical representation is as follow.

$$P_{ij} = Exp(U_{ij}) / \sum_j Exp(U_{ij}) \tag{2}$$

Here P_{ij} =Probability of decision maker i choose alternative j, U_{ij} =Utility of decision maker i choosing alternative j. Utility U_{ij} consists of two parts, namely direct utility V_{ij} and stochastic error ε_{ij}. Utility of a shipper choosing a container port is determined by factors from two aspects, namely merits of the port and the transportation condition to the port. Index evaluation system developed in last section can be considered as a suitable measure to indicate the merits, while transportation conditions include transportation cost, transportation time, transportation reliability ect, which can be changed to a generalized transportation cost index. When there are several transportation modes available, its calculation method is as follows.

$$C_{ij} = \frac{C_{R,ij}}{C_{R,ij} + C_{T,ij}} C_{R,ij} + \frac{C_{T,ij}}{C_{R,ij} + C_{T,ij}} C_{T,ij} = \frac{C_{R,ij}^2 + C_{T,ij}^2}{C_{R,ij} + C_{T,ij}} \tag{3}$$

Here supposing two kinds of transportation modes (road and railway) are available and $C_{R,ij}$ =generalized road transportation cost, $C_{T,ij}$ = generalized railway transportation cost. Therefore, shipper behavior in choosing a container port can be represented as follows.

$$V_{ij} = I_j^{r_1} / C_{ij}^{r_2}$$

$$P_{ij} = \frac{I_j^{r_1} / C_{ij}^{r_2}}{\sum_k I_k^{r_1} / C_{ij}^{r_2}}$$

Here $k = 1,...,n$ (*n: number of container port in a region*), I_k =merit of port k. If there are G_j containers in a city, then containers from city j to port i is as follows.

$$G_{ij} = G_j P_{ij} = G_j \frac{I_j^{r_1} / C_{ij}^{r_2}}{\sum_k I_k^{r_1} / C_{ij}^{r_2}} \tag{4}$$

G_{ij} =hinterland size of port i in city j. Total hinterland size of a port in a region can be obtained through summing G_{ij} city by city. Different from traditional hinterland definition, port hinterlands calculated here can overlay each other, and a city may be the hinterland of several container ports. We illustrate this dynamic hinterland idea with numerical test in next section.

5. NUMERICAL TEST

We take Bohai bay area as the test region. There are 5 ports in the region and 20 cities with over one million populations. We collected data on the five ports from port authorities and based on an interview with shippers and logistics companies we set $\gamma_1 = 2, \gamma_2 = 1$ to use the model to calculated the competition capacity and choice probabilities of each city of ports. The results are depicted in Fig. 2. Traditional, Shangyang was considered as the hinterland of Dalian port, however, from our study we can see that Tianjin port should attract 30% containers from Shenyang. The reason why most containers in Shengyang select Dalian as shipping port is because that Dalian and Shenyang are in the same province, they have a realization of each other and Tinajin did not develop port the market in Shenyan city. Our calculating results give information for regional container transportation scheduling, and container transportation scheme based on the analyses will create the largest social benefits.

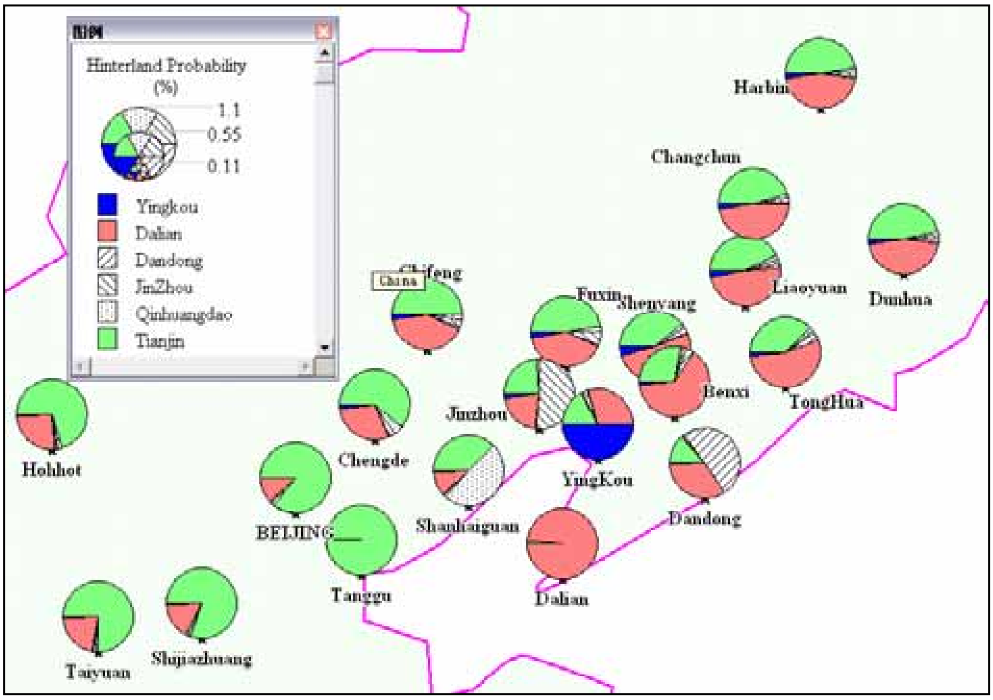

Fig. 2 Hinterland of the five Port in the Region

REFERENCES

Achabal, D.D., Gorr, W.L., Mahajan, V. (1982). MULTILOC: A multiple store location decision model, **Journal of Retailing 58 (summer), 5-25.**

Clarke, I., Bennison D., Pal, J. (1997). Towards a contemporary perspective of retail location, **International Journal of Retail and Distribution Management 25 (2), 59-69**.

Chou Chien-Chang et al (2003). A transportation demand split model for international ports in Taiwan area, **Journal of the Eastern Asia Society for Transportation Studies, Vol.5, 625-637**.

Fotheringham, A. (1983). A new set of spatial interaction models; the theory of competing destinations, **Environment and Planning A 15, 15-36**.

Fujino Naoaki *et al* (1995). No-cooperative game analysis of international container shipping behavior, **Proceeding of Infrastructure planning of JSCE, No.18-2, 517-520**.

Ghosh, A., Craig, S. (1991). FRANSYS: A franchise distribution system location model, J**ournal of Retailing 67 (winter), 466-495**.

Ghosh, A., Harche, F. (1993). Location-allocation models in the private sector: progress, problems and prospects, **Locational Science 1, 81-106**.

Hodgson, M. (1978). Towards more realistic allocation in location-allocation models: an integration approach, **Environment and Planning A 10, 1273-1286**.

Mark Birkin, Graham Clarke and Lee Douglas (2002). Optimizing spatial mergers: commercial and regulatory perspectives, **Progress in Planning 58, 229-318**
Nakanishi, M., Cooper, L.G. (1974). Parameter estimation for a multiplicative competitive interactive model least squares approach, **Journal of Marketing Research 1, 303-311**.

Noguchi Koji *et al* (2000). A Modeling for key airport preference of passengers and airlines under the condition of deregulation, **Proceeding of Infrastructure planning of JSCE, No.23-2, 195-198**.

Yano, K. (1993). Integration of spatial interaction models: towards a general theory of spatial interaction, **Geographical Reports of Tokyo Metropolitan University 28, 33-78.**

Su Yuhling *et a*l. (2003). A Study on integrated port performance comparison based on the concept of balanced scorecard, **Journal of the Eastern Asia Society for Transportation Studies, Vol.5,609-624**.

Takase Tatso, Morikawa Takayuki (1996). International air transportation demand analysis considering equilibrium between carriers and Passengers behavior, **Proceeding of Infrastructure planning of JSCE, No. 13, 769-776.**

Yang Zan (1996). An application of stackerlberg problem to international container movement, **Proceeding of the 1st JSPS-NUS Seminar on Integrated Engineering, 125-134**.

Yang Zan (1999) Analysis of container port policy by the reaction of an equilibrium shipping market, **International Journal of Maritime Policy and Management, Vol. 26, No. 4, 369-381.**

Yang Z.Z (2002.9). Microanalysis of shopping center location in terms of their retail supply **Quality and Environmental Impact, Journal of Urban Planning and Development, ASCE, Vol.128 No.3, 139-149.**

Zhang Chuqian, *et al* (2002). Dynamic crane deployment in container storage yards, **Transportation Research Part B 36 (2002) 537–555**.