Journal of the Eastern Asia Society for Transportation Studies, Vol.8, 2010

Optimization of Shipping Network of Trunk and Feeder Lines for Inter-Regional and Intra-Regional Container Transport

Zhongzhen YANG
Professor
College of Transport Management
Dalian Maritime University
1, Linghai RD, Dalian, China
Fax: +86-411-8472-6756
E-mail: yangzhongzhen@263.net

Kang CHEN
Doctoral Student
College of Transport Management
Dalian Maritime University
1, Linghai RD, Dalian, China
Fax: +86-411-8472-6756
E-mail: huaifei_qingwen@163.com

Abstract: This paper firstly analyzes the structure of the existing container shipping network, which covers several areas located respectively in two counties, and develops a new kind of shipping network that consists of trunk and feeder lines. Secondly, the paper constructs a bi-level programming model that can be used to optimize the container shipping network with the aim to minimize the generalized transport costs. Then the model is tested with container O-D data between the ports in the Surrounding Bohai area in China and two ports in the West of the USA. Through the test calculation, a feasible optimized shipping network consisting of trunk and feeder lines is founded for the case study area.

Key Words: Shipping Network, Trunk Line, Container Transport, Surrounding Bohai Area.

1. BACKGROUND

As is known to all, the aim of oceanic shipping is to realize the movement of the freights traded between two remote countries. Because the trade usually happens among several areas of the two sides, when there are several ports on each side, the foremost problems of liner companies are: which ports should be the hub ones and which should be the feeder ones? how to combine the trunk lines and feeder ones spatially and temporally, etc. However, at present, little liner companies engaging in shipping container between China and the USA operate on both trunk lines between the two countries and the intra-regional feeder lines simultaneously. This situation leads to the imperfect container shipping network, lowers the service level of container shipping and causes the complaint from the shippers.

Considering the characteristics of the container shipping network, it is necessary to design a pan-regional container shipping network that consists of trunk lines and feeder ones. It is also needed to optimize the shipping system. Thus, the paper puts forth an idea of network mixed by trunk and feeder shipping lines, and based on the new idea, an analytical model is constructed to optimize the network configuration. The results of this study are helpful for the operation of liner companies and useful for port construction and management.

2. LITERATURE REVIEW

Researches on optimizing network of trunk shipping lines can be found in many literatures. Some of them minimized the total cost, and some tried to maximize the benefit, while the left ones aimed to realize the shortest operational time. For instance, Brown *et al*. (1987) designed shipping lines and determined the sailing schedule for the tankers with enumeration method. He built an Elastic Set Partitioning Model to save costs for shipping companies. David (1986) defined the design of route line as an assignment problem of a series of ports. Cho and Perakis (1996) analyzed the fleet size for a container liner company and optimized the shipping lines. They gave alternative lines for different vessels and solved the problem with a linear programming model, and they further extended the model into a MIP (Mixed Integer Planning) one and put forth a plan to enlarge the fleet size.

Fagerholt (1999) studied the optimization of a container vessel fleet, which would be used to serve Norwegian coastal lines weekly. Because the method could be only used to manage the vessels with the same running speed, Fagerholt and Rotten (2004) further presented a new algorithm to handle the fleet with different running speeds and carried our an application. Perakis and Jararmillo (1991) designed an Integer Linear Programming Model to optimize shipping lines and considered the integration of ports, lines and vessels based on freight O-D matrix.

Hsu and Hsieh (2007) optimized the combination of trunk lines and feeder lines for a shipping company, the designed combination could minimize the system cost for the company. In the model, the costs were divided into shipping and storage ones, and the trunk and feeder lines were designed through considering the trade-off between the two costs.

Moreover, Krishan and Vickson (1992) studied the problem of line design when several ports are available to build a non-linear programming model, which maximized the profit of the vessel and is subject to vessel capacity and sailing time. The model successfully solved the problem of determining hub ports, feeder ports and line determination for a container vessel. However, the model could only deal with one line and was difficult to be solved. Afterwards, they used Lagrangian relaxation method to build a model to design the shipping line network for multi-vessels and multi-ports.

Since 2000, some quantitative studies on line optimization have been done in China. However, study on the dynamic optimal combination of trunk lines and feeder ones has no substantial development. Zhao (2006) studied the problems such as the feasibility of lines, vessel assignment and schedule making. According to the relationships between the shipping capacity and the volume, linear programming models minimizing operation cost and maximizing shipping volume were built respectively. Fang (2002) calculated shipping cost of the network of feeder lines covering ports around the Pacific. In the study, competition of COSCON is analyzed in terms of its shipping capacity, shipping volume and operation ability. Hub ports respectively in the two sides of the Pacific were determined. Shen (2003) discussed the optimization methods for liner lines, the model to evaluate the operation benefit and the method to optimize a single container liner line were studied. The shortage of the study is that the model can only deal with one voyage and did not consider the berthing sequence practically. Wu (2004) optimized the whole shipping network with systematic analysis method to establish a container route selection model.

Wang and Jin (2006) analyzed the hub-spoke style network and discussed the China’s container shipping in terms of lines, frequency, transshipment sites and regional system qualitatively. Wu *et al.* (2006) built a stochastic route optimization model for uncertain demand based on the attribute analysis of the seaborne container transport. The model aimed to maximize the profit during the transport subject to the constraints of link capacity, dead weight, balance of empty and heavy containers, and was solved with chance constrained programming method. Ren (2007) studied the berthing-port selection problem of liners. He considered the cost of feeder transport in the line design and combined transshipping port selection with line planning to develop a programming model with multi-objectives, such as the maximized profit and the shortest time of one voyage. He did case study for the port selection by taking lines between China and Japan as an example to verify the accuracy of the model. Jiao (2008) defined the optimization problems of coastal shipping network in the context of one hub port and built a MIP model to optimize the coastal shipping network in terms of systematic cost. And he found the optimal network of feed lines and the best operation scheme with Particle Swarm Algorithm for feeder line container shipping among ports surrounding Bohai bay.

This paper mainly studies on the optimization of container shipping network between two trans-oceanic regions. We suppose that demand of container transport exists between ports in the two regions respectively and shipping companies operates several kinds of container vessels. Then, we select ports for trunk and feeder lines simultaneously and make the shipping operation scheme. The paper studies the dynamic optimization decision-making of the design of trunk and feeder lines and builds a non-linear MIP model to optimize the configuration of inter and intra regional container shipping network. Based on the volumes of the transported containers between the ports respectively in Bohai bay area of China and the West of the USA, shipping network that consists of inter-regional lines and intra-regional lines is designed with the model. During the calculation, Genetic Algorithm (GA) is used.

3. DESIGN OF SHIPPING NETWORK

3.1 Classification of Container Shipping Lines

There are circle shipping line, pendulum shipping line, and hub-and-spoke shipping line. In circle line, the container vessel sails from one port to another in one direction. In one voyage, each port is only called once. In pendulum line, a vessel firstly sails to the destination calling the ports one by one, and then sails back on the opposite direction. In one voyage, the intermediate ports are called twice. In hub-and-spoke line, a vessel sails between two continents and only calls one hub port in each continent and the containers from and to the no-called ports will be carried by feeder lines that orient and end at the hub ports. This is because that calling fewer ports can raise the operational speed of the vessels and then to realize scale economy of the big vessels. However, hub-and-spoke line, many containers are loaded or unloaded more than twice. As a result, the transport costs may increase.

3.2 Structure of Container Shipping Network

In order to represent container shipping process in a network, we divide nodes that represent ports in the network into real nodes, dummy nodes and dummy links. Thus, the processes of loading, unloading and transshipment can be described as the movements from a dummy node to a real node through the dummy link. In this network a container can move from one port to any other ports. For instance, Fig. 1 shows the network only consisting of a trunk line that is used to transport containers from one country to another over oceans. Fig. 2 presents a feeder line in one side (let say country A) that is used to collect containers from several small ports to the hub port. It can be seen that Port 1 is called by both lines. In fact, the two lines form a shipping network because Port 1 can be used to transfer containers from ports in Country A to another country, vice versa. After adding a dummy node and two dummy links in Port 1, a shipping network consisting of a trunk line and a feeder line is constructed as shown in Fig. 3.

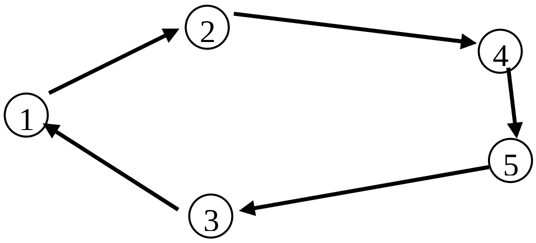

Fig. 1 Trunk line over Oceans

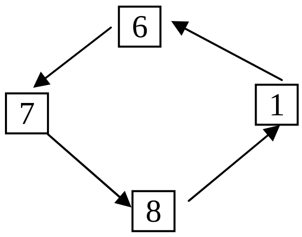

Fig. 2 Intra-Region Feeder Line

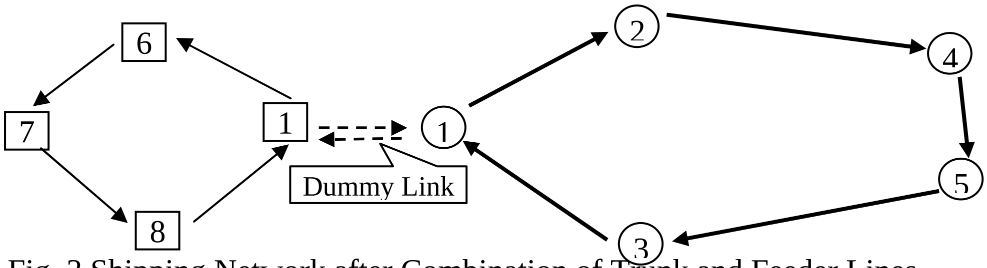

Fig. 3 Shipping Network after Combination of Trunk and Feeder Lines

3.3 Optimization of Shipping Network of Trunk and Feeder Lines

Here we set the optimization of the shipping network as a bi-level programming problem. It aims to design the optimal shipping routes for a given fleet and the known container volume between countries. The upper model determines a trunk line, the being called ports and the calling order, while the lower one finds a number of feeder lines to cover all the feeder ports in the context of the being designated hub port.

For a trunk line, the rules of selection of the being called port are as follow: 1) Sufficient demand; 2) Schedule permission, the frequency of the line should be guaranteed; 3) Convenience of transshipment, the being selected ports should be helpful to the optimization of shipping network and the hub port development; 4) Port conditions satisfying the berth of large vessels; 5) Helpful for balancing the empty and heavy containers. For the feeder lines, the rules are: 1) Voyage cycles must be shorter than the headway of the trunk lines; 2) Coverage rules, all ports with containers must be called. Moreover, in order to be convenient for the modeling, some assumptions are made according to the attributes of international container shipping:

- Weekly container flows between the origin and destination ports are known.
- Capacities of vessels for trunk and feeder lines are 6800 TEU and 650 TEU respectively and every port can handle them.
- On normal condition, average speeds of vessels on trunk and feeder lines are 22kn and 11kn respectively. Average handling rates of ports are known.
- Costs, available compartments of each link are known.
- Containers can not be transferred twice.
- Cost of transshipment is included in the feeder line.
- The storage cost due to early arrival of the feeder line is neglected.
- Containers between each pair of ports can choose the feasible routes freely. If there are 2 lines calling the same port simultaneously, transshipment may be done.
- The time and cost from the consignment to the loading and transshipment are neglected, while needed cost for transshipment between the trunk and feeder lines are considered.

Then, let $X_i = 1$ if a vessel on trunk line calls port i, else $X_i = 0$; $X_{ij} = 1$ if a vessel on trunk line goes through link (i, j), else $X_{ij} = 0$; $Y_i^k = 1$ if a vessel on feeder line calls port i, else $Y_i^k = 0$; $Y_{ij}^k = 1$ if a vessel on feeder line goes through link (i, j), else $Y_{ij}^k = 0$, thus the optimization model for the network of the trunk and feeder lines that minimizes the total transport cost in the context of inter-continental container transport is as Eq.(1) to Eq.(15).

$$Min \qquad z = \sum_{i}^{n}\sum_{j}^{n} X_{ij} C_{ij} + \sum_{i}^{n}\sum_{j}^{n}\sum_{k}^{K} Y_{ij}^{k} C_{ij}^{k} \tag{1}$$

Here, $\sum_{i}^{n}\sum_{j}^{n} X_{ij}C_{ij}$, $\sum_{i}^{n}\sum_{j}^{n}\sum_{k}^{K} Y_{ij}^{k}C_{ij}^{k}$ are shipping costs of trunk and feeder lines respectively, its detailed structures are shown in Eq. (2) and Eq. (3)

$$\begin{aligned}\sum_{i}^{n}\sum_{j}^{n} X_{ij}C_{ij} &= \sum_{i}^{n}\sum_{j}^{n}[\frac{L_{ij}X_{ij}}{v_1 \times 24} + (\frac{Q_i^l + Q_i^d}{\rho_i \times 24} + t_i)X_i] \times C_c \\ &+ \sum_{i}^{n}\sum_{j}^{n}\left[\frac{L_{ij}X_{ij}}{v_1 \times 24} \times a_1 \times b + \frac{L_{ij}X_i}{v_1 \times 24} \times a_2 \times h + (\frac{Q_i^l + Q_i^d}{\rho_i \times 24} + t_i)X_i \times a_3 \times h\right] \\ &+ \sum_{i}(DWT \times PF \times X_i) + \sum_{i}^{n}(Q_i^l + Q_i^d) \times X_i \times w\end{aligned} \tag{2}$$

In the right side of Eq.(2), the first item means the fixed cost of one voyage of trunk line, second one is the fuel cost that includes shipping fuel cost, in port fuel cost and waiting fuel cost, and the third one is the port tariff of one voyage, while the last item is loading and unloading fees of one voyage.

$$\begin{aligned}\sum_{i}^{n}\sum_{j}^{n}\sum_{k}^{K} Y_{ij}^{k}C_{ij}^{k} &= \sum_{i}\sum_{j}\sum_{k}[\frac{L_{ij}Y_{ij}^k}{v_2 \times 24} + (\frac{Q_i^l + Q_i^d}{\rho_i \times 24} + t_i)Y_i^k] \times C_c \\ &+ \sum_{i}\sum_{j}\sum_{k}\left[\frac{L_{ij}Y_{ij}^k}{v_2 \times 24} \times a_1 \times b + \frac{L_{ij}Y_i^k}{v_2 \times 24} \times a_2 \times h + (\frac{Q_i^l + Q_i^d}{\rho_i \times 24} + t_i)Y_i^k \times a_3 \times h\right] \\ &+ \sum_{i}\sum_{k}\left[DWT \times PF \times Y_i^k\right] + \sum_{i}\sum_{k}(Q_i^l + Q_i^d) \times Y_i^k \times w\end{aligned} \tag{3}$$

Means of items in the right side of Eq.(3) are similar to those in Eq.(2), but correspond to the feeder line. The constraints of the objective function are as follow.

- **Flow Balance in Transshipment Ports**

$$\mathrm{Q}_{P_k}^{d} = \sum_i Y_i^k \mathrm{Q}_i^l, \quad \mathrm{Q}_{P_k}^{l} = \sum_i Y_i^k \mathrm{Q}_i^d \tag{4}$$

Eq.(4) means that in a voyage of the trunk line, the loading (or unloading) volume of trunk line in a hub port should equal to the sum of unloading (or loading) volumes in its all feeder ports.

- **Frequency Constraint of Trunk line**

$$\sum_{i}\sum_{j}\frac{L_{ij}X_{ij}}{v \times 24} + \sum_{i}(\frac{Q_i^l + Q_i^d}{\rho_i \times 24} + t_i)X_i \le T \tag{5}$$

Eq.(5) means the frequency of trunk line should be over a limit that can guarantee the competition of shipping company on the market.

- **Frequency Constraint of Feeder Line**

$$\sum_{i}\sum_{j}\frac{L_{ij}Y_{ij}^k}{v_2 \times 24} + \sum_{i}Y_i^k(\frac{Q_i^l + Q_i^d}{\rho_i \times 24} + t_i) \le \Delta T \qquad \forall k \in K \tag{6}$$

Eq.(6) means the shipping cycle of a feeder line must be shorter than the head way of the corresponding trunk line.

- **Balance of Loading and Unloading in each Port**

$$Q_i^l = Q_i^d \qquad \forall i \in V \tag{7}$$

Eq.(7) is used to control the balance of the loading and unloading containers. When the loaded heavy containers are more than the unloaded ones in a port, it needs to load some empty containers to balance the container boxes.

- **Capacity Constraint on Trunk lines**

$$X_i Q_i^{out} \le Q_m \qquad \forall i \in N \tag{8}$$

Here, $Q_i^{out} = Q_i^{in} + Q_i^l + Q_i^d$ (9)

- **Capacity Constraint on Feeder Lines**

$$Y_i^k Q_i^{out} \le Q_f \qquad \forall k \in K \tag{10}$$

- **Vessels of Feeder Lines Starting from and Ending at the Same Hub Ports**

$$\sum_i Y_{iP_k}^k = 1 \qquad \forall k \in K \tag{11}$$

$$\sum_j Y_{jP_k}^k = 1 \qquad \forall k \in K \tag{12}$$

- **Feeder Ports are called only once**

$$\sum_{i \in V, i \notin \{P_k\}} Y_{ij}^k = Y_j^k \qquad \forall j \in V \tag{13}$$

$$\sum_{j \in V, j \notin \{P_k\}} Y_{ji}^k = Y_i^k \qquad \forall i \in V \tag{14}$$

$$\sum_{k \in K} Y_i^k = 1 \qquad \forall i \notin \{P_k\} \tag{15}$$

Other variables and parameters in the model are as following: $G = (V, E)$ is inter-regional container shipping network; $V = \{1, 2, \ldots, I, \ldots, j, \ldots, n\}$ is port set; $E = \{(i, j)|i, j=0, 1, \ldots, n; i<>j\}$ is set of links between any ports in V; i, j is serial number of ports; L_{ij} is the shipping distance between *i* and *j*; V_1 is the speed of vessels of trunk lines; V_2 is the speed of vessels of feeder lines; Q_i^l is loading volume of containers at port *i*; Q_i^d is unloading volume of containers at port *i*; t_i is the time of inbound, outbound and waiting in a port; a_1 is daily consumed heavy fuel of the vessels with speed *v* in trunk line; a_2 is daily consumed light fuel of the vessels with speed *v* in trunk line; a_3 is daily consumed light fuel for in-port operation of the vessels in trunk line; b is price of heavy fuel; h is price of light fuel; C_c is daily fixed cost of vessel in trunk line; C_f is daily fixed cost of feeder vessel; DWT is the dead weight of vessel in trunk line; PF is port tariff per DWT; W_i is container loading charge in port *i*; P_i is tax rate per imported container; T is shipping cycle of the trunk line; ΔT is shipping interval of trunk line K is number of feeder lines; $P_k \in V$ is hub port in k^{th} feeder line; $\{P_k\} = \{P_1, P_2, \wedge, P_k\}$ is the set of transshipment ports on trunk lines.

4. CASE STUDY

There are steady shipping demand of trade containers between the ports in China's Bohai area and the West in the USA. At present, exported containers in China's side to the USA have been transshipped at Pusan or Yokohama. This is because that one shipping company could not collect enough containers for direct shipping. However, there should be a direct shipping line crossing the Pacific and several feeder lines surrounding the Bohai bay. This kind of shipping network of trunk and feeder lines may minimize the total shipping cost.

4.1 Input Data

One of the data is container O-D flow matrix between ports surrounding Bohai bay in China and two ports in the West of USA, which is shown in Table 1. The maritime distances between ports are calculated with software of Netpas. Moreover, the port operation efficiency, time of inbound, outbound and waiting for berth, loading and unloading cost, and port tariffs are collected and listed in Table 2. The daily fixed costs of different kinds of vessels are shown in Table 3. Moreover, during the calculation the average fuel price of 2007 is used, they are F.O=3600 RMB/ton, D.O=6000 RMB /ton. The weight of vessel of 6800 TEU is 80,000 ton and the weight of vessel of 650 TEU is 10,000 ton. The shipping cycle of trunk line T=35 days and the shipping interval ΔT =7 days.

Table 1 Container O-D Flow Matrix

O	D	TEU	O	D	TEU	O	D	TEU
Auckland	Dalian	250	Jinzhou	Auckland	10	L.A	Yantai	300
Auckland	Dandong	20	Jinzhou	L.A	30	L.A	Yingkou	300
Auckland	Jinzhou	20	Jingtang	Auckland	10	Qinhuangdao	Auckland	10
Auckland	Jingtang	15	Jingtang	L.A	30	Qinhuangdao	L.A	30
Auckland	Longkou	15	Longkou	Auckland	10	Qingdao	Auckland	450
Auckland	Qinhuangdao	15	Longkou	L.A	30	Qingdao	L.A	1,350
Auckland	Qindao	600	L.A	Dalian	750	Rizhao	Auckland	20
Auckland	Rizhao	30	L.A	Dandong	60	Rizhao	L.A	60
Auckland	Tianjin	450	L.A	Jinzhou	60	Tianjin	Auckland	350
Auckland	Weihai	25	L.A	Jinzhou	45	Tianjin	L.A	1,050
Auckland	Yantai	100	L.A	Longkou	45	Weihai	Auckland	15
Auckland	Yingkou	100	L.A	Qinhuangdao	45	Weihai	L.A	45
Dalian	Auckland	200	L.A	Qingdao	1,800	Yantai	Auckland	80
Dalian	L.A	600	L.A	Rizhao	120	Yantai	L.A	240
Dandong	Auckland	10	L.A	Tianjin	1,350	Yingkou	Auckland	80
Dandong	L.A	30	L.A	Weihai	75	Yingkou	L.A	240

Table 2 Port Efficiency, Time of Inbound, Outbound and Waiting for Berth, Loading and Unloading Price, Port Tariff

	Efficiency (TEU/h)		Time (h)		Price of Heavy Container (RMB/TEU)	Price of Empty Container (RMB/TEU)	Tariff (RMB/Total Ton)
	Trunk line	Feeder Line	Trunk line	Feeder Line			
Dalian	140	70	2	2	310	240	12
Qingdao	140	70	2	2	310	240	12
Tianjin	140	70	2	2	310	240	12
Yantai	90	50	3	2	300	230	12
Weihai	60	50	3	2	300	230	12
Yingkou	90	50	3	2	300	230	12
Dandong	40	50	4	2	300	230	12
Jinzhou	40	50	4	2	300	230	12
Qinhuangdao	40	50	4	2	300	230	12
Longkou	40	50	4	2	300	230	12
Jingtang	40	50	2	2	300	230	12
Rizhao	90	50	2	2	300	230	12
Auckland	140	70	2	2	350	280	12
L.A.	140	70	2	2	350	280	12

Table 3 Daily Fixed Costs of Different Kinds of Container Vessels

Type	Cost	Type	Cost
8000 TEU	118,000 RMB/Day	2000 TEU	46,000 RMB/Day
6000 TEU	95,000 RMB/Day	1000 TEU	26,000 RMB/Day
5000 TEU	84,000 RMB/Day	800 TEU	22,000 RMB/Day
3000 TEU	57,000 RMB/Day	600 TEU	16,000 RMB/Day
		300 TEU	10,000 RMB/Day

4.2 GA Algorithm

➢ **Coding Chromosome**

Here, a chromosome consists of four sub-strings, the first one has n genetics to represent X_i (n=the number of ports); the second one has $n \times n$ genetics to represent X_{ij}; the third one has $n \times k$ genetics, while k is the unknown number of the branch lines, during the calculation supposing k is a number among 2-4 to represent Y_i^k; the forth one has $n \times n \times k$ genetics to represent Y_{ij}^k.

The four sub-strings interact each others, for example, if we design the trunk and feeder lines in the context of ten ports in two regions (5 ports in each region), the chromosome can be divided into: Sub-string 1=0-0-1-0-1-1-0-0-1-0, which means that ports 3, 5, 6 and 9 are in the trunk line; In this case, Sub-string 2 is shown in Table 4.

Table 4 Code of Sub-string 2

	1	2	3	4	5	6	7	8	9	10
1										
2										
3					1					
4										
5									1	
6			1							
7										
8										
9						1				
10										

For Sub-string 3, supposing k=2, string (1-1-1-1-0-0-0-0-0-0-0-0-0-0-0-0-1-1-1-1) means that feeder Line 1 calls pots 1, 2, 3 and 4, and feeder Line 2 calls pots 7, 8, 9 and 10. Sub-string 4 is coded based on the former threes and an example is shown in Table 5. It means that in Leeder Line 1 (3-1-2-4-3), port 3 is a trunk port; and in Feeder Line 2 (9-10-8-7-9), port 9 is a trunk port.

Table 5 Code of Sub-string 4

	1	2	3	4	5
1		1			
2				1	
3	1				
4			1		
5					

	6	7	8	9	10
6					
7				1	
8		1			
9					1
10			1		

➢ **Fitness Function and Constraints**

The object function is directly used as the fitness function and a punishment function is used to deal with the constraints.

- **Selection, Crossover and** Mutation

Sending several chromosomes in the parent generation with bigger fitness directly into the child generation, and then carrying out crossing and mutating calculations to generate a new generation, and comparing the new chromosomes with the old ones to choose the bigger ones. Multi-points crossover is used and crossover is done to sub-strings respectively. For the mutation, choosing two sites in a chromosome randomly and reversing the genetics between the sites to get a new chromosome.

- **Parameters in the Algorithm**

The parameters of GA are set as: Population size =50; Generation gap=0.8; Crossover ratio =0.75; Mutation ratio =0.05; when no changes happening for 10 generations, changing mutation ratio to 0.7; Maximum iteration =1000.

4.3 Results and Discussion

- **Output of the Calculation**

Setting K=1, 2, 3, 4 respectively (means the shipping network consists of 1 trunk line and 1-4 feeder lines). Fig. 4 shows the changes of the fitness when K=3. It can be seen that after 700 times of calculation, the fitness tends to converge. The fitness in other three situations (K=1, 2, 4) have the similar trend. The solutions and shipping costs in the 4 cases are shown in Table 6. It can be found that the total shipping cost of the network consisting of one trunk line and three feeder lines is the lowest (36,655,000RMB).

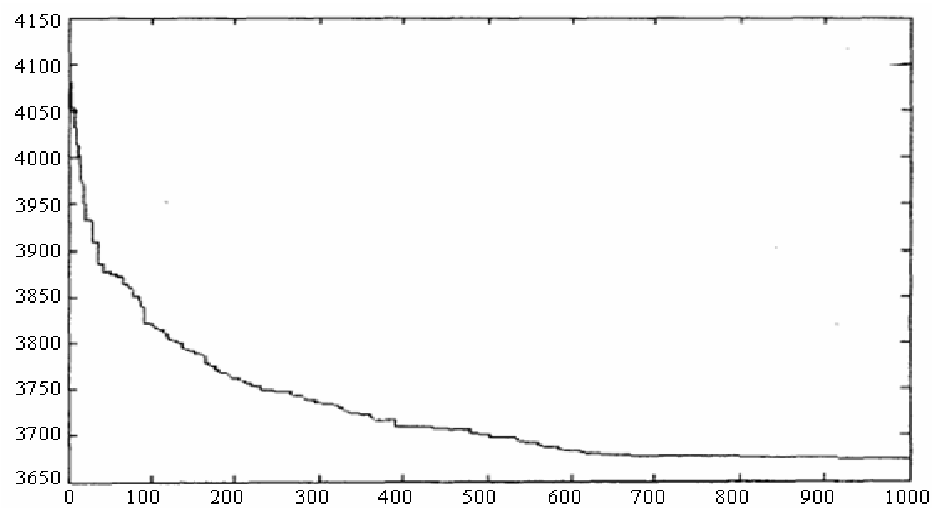

Fig. 4 Value of the Fitness in the Case of K=3

Table 6 Comparison of the Costs in the 4 Situations

Case	Trunk lines	Cost of Trunk (M. RMB)	Feeder Lines	Cost of Feeder (M. RMB)	Total Cost (M. RMB)
K=1	1-6-9-11-3-4-12-2-14-13-1	37.587	1-8-10-5-7-1	1.81	39.439
K=2	1-3-12-2-13-14-1	33.656	1-10-4-5-7-1	1.721	37.055
			1-11-9-8-6-1	1.677	
K=3	1-3-2-13-14-1	32.894	1-10-4-5-7-1	1.721	**36.655**
			1-11-9-8-6-1	1.677	

			2-12-2	0.363	
K=4	1-3-2-13-14-1	32.894	1-10-4-5-1	1.539	37.715
			1-7-6-1	1.288	
			3-11-9-8-3	1.632	
			2-12-2	0.363	

Note: 1=Dalian, 2=Qingdao, 3=Tianjin, 4=Yantai, 5=Weihai, 6=Yngkou, 7=Dandong, 8=Jinzhou, 9=Qinhuangdao, 10=Longkou, 11=Jingtang, 12=Rizhao, 13= Auckland, 14=L.A.

➢ Network Adjustment

In order to simplify the calculation, the above network is obtained under the assumption that there is only one type of vessel for the feeder line. However, the assumption is un-reasonable because the results shows that the third feeder line only calls one feeder port (Rizhao Port), the weekly shipping volume is 150 TEU and shipping cycle is only 2.5 days. Thus, the vessel of 650TEU is too large for this line. The smaller vessel should be used for the third feeder line. Therefore, we use a vessel of 80 TEU to operate this line twice a week. After the adjustment, used vessels and the designed shipping lines are shown in Table 7 and the corresponding shipping network is shown in Fig. 5. In this case, the total shipping cost changes to 36.517 million RMB which is 0.108 million RMB less than the original one.

Table 7 Used Vessels and Designed Shipping Lines

Vessel	Capacity	Line	Lenth (nmile)	Frequency	Time of One Voyage	Cost/Voyage (M. RMB)
1	6800	1-3-2-13-14-1 (Trunk)	12204	1 /week	33days	32.894
2	650	1-10-4-5-7-1 (Feeder)	630	1/week	6days	1.721
3	650	1-11-9-8-6-1 (Feeder)	677	1/week	6days	1.677
4	80	2-12-2 (Feeder)	328	2/week	2.5days	0.255

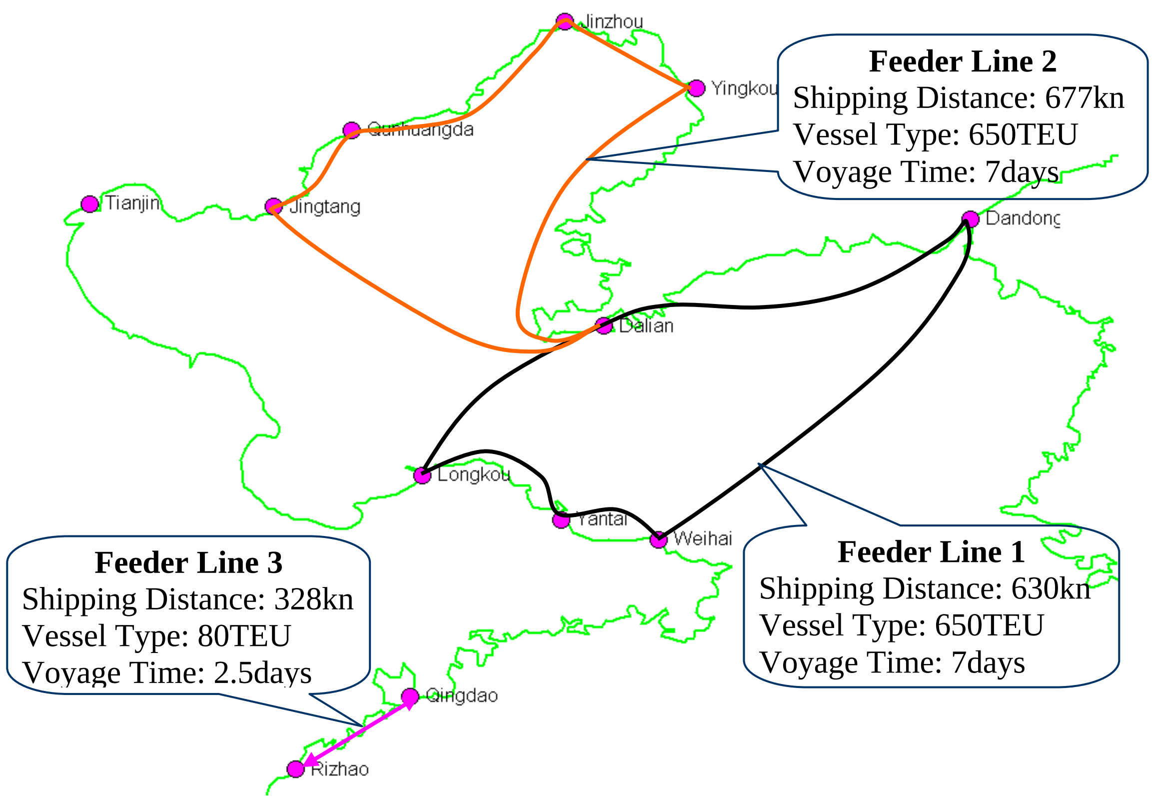

Fig. 5 Feeder Lines after the Adjustment

➢ **Discussion**

It can be seen that the first and second feeder lines call Dalian port, which is a hub port in the trunk line. Based on this result, it can be said that Dalian port plays an important role in Bohai bay area. Since Tianjin port is far from other ports, no feeder line calls Tianjin port. It means that Tianjin port must be a hub port on the trunk line and can not be as a transshipping port. Although Qingdao port has a great volume of containers, it is located nearly beyond Bohai bay, thus possibility of containers in other ports being transshipped at Qindao port is very small. While, Rizhao port is near Qindao port closely, the containers in Rizhao port may be shipped by barge to Qingdao and transshipped to the West of the USA. Both Yingkou port and Yantai port are developing fast recently, their throughputs of foreign trade increases fast, however, the calculated results show that they are still important feeder ports rather than the hub ones. They may be hub ports if voyage cost such as fuel prices, loading and unloading costs change greatly.

Transshipment of containers should be encouraged greatly in Surrounding Bohai bay area. Dalian port should be positioned as a hub port for port to port transshipment, while Tianjin port and Qindao port may be developed into hub ports for hinterland to port transshipment. As important feeder ports, Yingkou port, Yantai port and Rizhao port should develop feeder shipping greatly and other ports in Surrounding Bohai bay area should be as feeder ports to feed containers to Dalian port.

Although in shipping and maritime industry, types of contracts and regional policies may turn out more important than optimization and low cost strategies, currently in Surrounding Bohai bay area trunk and feeder lines are operated by different companies. In order to increase their container thoughputs, ports authorities encourage shipping companies to operate trunk lines and then operate feeder lines by themseves. It results in a cut-throad competition and all ports could not attract enough containers for the truck lines. Now some ports in this area begine to cooeprate with aim to optimize the use of the infrastructure, thus our mehtod may offer them a tool to designde a shipping netwrok that may generate a win-win situation.

5 CONCLUSIONS

This paper analyzed the network structure of inter-continental container shipping lines, built a model to optimize the container shipping network of trunk lines and feeder lines to minimize the total transport cost. The model is applied to the network design of liner shipping between ports surrounding Bohai bay in China and two ports in the West of the USA. The calculated results are helpful to shipping companies and the port authorities.

REFERENCE

Brown, G. G., Graves, G. W. and David, R. (1987) Scheduling Ocean Transportation of Crude Oil. **Management Science**, Vol.33, No.3, 335-346.

Cho Seong-cheol and Perakis A. N. (1996) Optimal liner fleet routing strategies. **Maritime Policy and Management**, Vol.23, No.3, 249-259.

David, R. (1986) Short-term scheduling of vessels for shipping bulk or semi-bulk commodities originating in a single area. **Operation Research Society of American**, Vol.34, No.1, Jan, 164-173.

Fagerholt, K. (1999) Optimal fleet design in a ship routing problem. **International Transactions in Operational Research**, Vol.6, Issue 5, 453-464.

Fagerholt, K. and Rotten, D. (2004) Ship routing and scheduling: status and perspectives. **Transportation Science**, Vol.38, Issue 1, 1-18.

Fang Liang (2002) Study on Development Strategy of COSCON Center Port. **Master Dissertation**, Dalian Maritime University.

Hsu Chaug-Ing and Hsieh Yu-Ping (2007) Routing, ship size, and sailing frequency decision-making for a maritime hub-and-spoke container network. **Mathematical and Computer Modelling**, Vol.45, Issue 7-8, 899–916

Jaramillo, D. I. and Perakis, A. N. (1991) Fleet deployment optimization for liner shipping Part 2. **Maritime Policy and Management**, Vol.18, No.4, 235-262.

Jiao Ning-Bo (2008) Optimization Research on the Coastal Container shipping Network of Branch Lines. **Master Dissertation**, Dalian Maritime University.

Krishan, R. and Vickson, R.G. (1992) Routing Container Ships Using Lagrangean Relaxation and Decomposition. **Transportation Science**, Vol.25, No.3, 201-214.

Ren Fei (2007) Research on Ports Selecting Model for Container Lines. **Master Dissertation**, Dalian Maritime University.

Shen Xue-Chao (2003) Research on Line Optimization of Container Liners. **Shipping Management**, Vol.10, 18-21.

Wang Cheng-Jin and Jin Feng-jun (2006) Organization Networks of Chinese Marine Container Transportation. **Scientia Geographica Sinica**, Vol.26, No.4, 4392-4401.

Wu Wen-Yi (2004) Study on Path option of container transport based on Shipping Alliance. **Master Dissertation**, Shanghai Maritime University.

Wu Zhen-Ye et al. (2006) Selection of Container Shipping Routes, **Journal of Southwest Jiaotong University**, Vol.41, No.3, 269-272.

Zhao Gang (2006) International Shipping Management. **Dalian Maritime University Press**, Dalian, China.