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The Optimization of Ningbo Zhoushan Port Container Sea-Rail Combined Transportation Network Routes

*Guiyun Liu, *Huijun Wu

* The Faculty of Maritime, Ningbo University, China, No. 818, Fenghua Road, Ningbo, Zhejiang, 315211, (liuguiyun@nbu.edu.cn)
** The Faculty of Maritime, Ningbo University, China, No. 818, Fenghua Road, Ningbo, Zhejiang, 315211, (524591352@qq.com)

Abstract

The container sea-rail combined transportation model increasingly becomes a trend for the development of container transportation system for its low cost, high efficiency, and low energy consumption, and the network routes optimization becomes more and more important. This paper focuses on the inland transportation networks of Ningbo Zhoushan Port container sea-rail combined transportation which constitutes the research subject. Limitations of transit time, transit cost and transit frequency are also taken into account, and a multi-objective optimization model for transportation routes is built with the minimum total cost. A discrete particle swarm optimization algorithm is applied to solve the research problem. Taking routes of Ningbo to Zhengzhou and Ningbo to Chongqing as examples, the paper works out the best transportation routes and transportation way under the condition of equal cost and time weight. Compared with the current transport lines, the total costs are lower. The results provide a reference for the layout of inland networks nodes and routes of Ningbo Zhoushan Port container sea-rail combined transportation.

Key words

Integrated transportation, routes optimization, discrete particle swarm algorithm, sea-rail combined transportation, container

1. Introduction

Sea-rail combined transportation becomes the important transportation mode of container cargo because of its high speed, security, environmental-friendliness and low cost. The Ningbo Zhoushan port is one of China's well-known container ports. Besides, it is also a strategic stronghold of China's Silk Road Economic Belt and 21st-Century Maritime Silk Road (hereinafter referred to "One Belt and One Road"). Therefore, the research on the optimization of container sea-rail combined transportation network routes is of great significance to improve the efficiency of port service and to promote the development of ports and its hinterland.

Given the importance of container sea-rail combined transportation, scholars at home and abroad have been engaged into many researches on its network layout. Rodrigue and Notteboon (2012) focused on rail-based dry ports in North-American and European, pointed out that many different forms and shapes within their respective intermodal rail systems are at an important position. A.H. Gharehgozli et al. (2015) researched on developing new container terminal technologies and OR directions or models in seaport, such as rail container terminals, to improve container handling and operating efficiency. M. Dotoli et al. (2015) provides a timed petri nets model for simulating and evaluating the performance of key elements of intermodal freight transportation to identify the bottlenecks and test different solutions. Kim and van Wee (2011) considered the relative importance of cost and geometric factors to the break-even distance for intermodal freight, founded that the geometric and handling costs are not more important than transport costs. Taking into consideration the comprehensive transportation network, Boussedjram et al. (2004) adopted the strategy of two-way research and came up with an idea of how to calculate the shortest distance under the condition of minimum transportation time between departures and destinations. Teodor Goabriel Crainie and Kap Hwan Kim (2007) established a linear programming model which minimized the total cost and met the demands of nodes supply as well, through which the distribution of cargo flow and the number of transfer nodes available for use in transportation network were calculated. Ekki D Kreutzberger (2008) constructed the optimization model with shortest distance and minimum time as objective functions, regardless of cost. T.S.Chang (2008) constructed a model of route optimization with multi-objectives after giving full consideration of transportation time and cost. Tristram (2010) analyzed two approaches of building multi-modal transportation network and then put forward the model of optimized routes with multi-objectives based on the minimum time in urban traffic, which was employed to improve the optimized algorithm to gain feasible results. Zhang (2012) established a model for container sea-rail combined transportation network optimization, of which the objective function was focused on the minimum container transportation cost and transit cost. Zhang et al. (2013) built a model of route optimization with double objectives after considering the transportation cost and time considered as well. They proposed binocular mark label set algorithm to get the pareto optimal path. The calculation results could provide the reference for sea-rail combined transportation operator to choose reasonable transportation routes. Wang (2014) constructed an optimization model of combined transportation with single task or multi-task on the behalf of multi-modal transport operator, based on the study on influential factors of multimodal transport and the selection of transportation routes. As a result, the best result was obtained through utilizing the simulated annealing. Wang (2014) probed into the configuration problem of inland container transportation nodes and examines the optimized approach of cargo distribution of transportation network. Then, an optimized approach of transportation routes was put forward with random characteristics of nodes operation. Based on efforts made above, the best transportation plan of inland container transportation was made out through data analysis. Based on researches mentioned above, this paper centers on inland transportation networks of Ningbo Zhoushan Port container sea-rail combined transportation and gives a full consideration to those influential factors such as transportation time, cost and transit frequency. The optimization model of network routes is set up and the discrete particle swarm algorithm is applied, which aims at providing reference for the construction of inland nodes and optimization of route layout of Ningbo Zhoushan port sea-rail combined transportation network.

2. The current situation

2.1 Network nodes

The container sea-rail combined transportation network nodes mainly include ports, railway container station and inland dry ports, etc. The Ningbo Zhoushan port contains 13 dry ports, including Xinchang, Yiwu, Jinhua, Yongkang, Lanxi, Quzhou, Shaoxing, Xiaoshan, Keqiao, Fuyang, Shangrao, Yingtan, Xiangyang, all of which are in good condition. The major cities, such as Hangzhou, Nanchang, Zhuzhou, Wuhan, Chongqing, Chengdu, Lanzhou, Xi 'an, Urumqi, etc, all distribute on the container sea-rail combined transportation network nodes.

2.2 Network routes

The transport corridor for container sea-rail combined transportation is formed on the basis of the network nodes. The Ningbo Zhoushan port container sea-rail combined transportation network routes are distributed in four directions: the northwest, the west, the southwest and the south.

(1) The northwest. Traveling across Longhai line, Jingjiu line, Ningxi line, Huhanrong line and Jiujingqu line, the container sea-rail combined transportation route connects Ningbo, then Hnagzhou, Nanjing, Zhengzhou, Lanzhou, Xi'an, Urumqi and other cities.

(2) The west. The transportation route starts from Ningbo to Hefei, Wuhan, Chengdu, Chongqing and other cities in the west, running across Xiaoyong line, Jiujingqu line, Qianzhangchang line, Yuhuai line and Hukun line.

(3) The southwest. The southwest transportation network route runs from Ningbo to Nanchang, Zhuzhou, Guiyang, Kunming and other cities, going across Zhegan line, XiangQian line and Guikun line.

(4) The south. Taking advantage of Taizhou-Wenzhou railway, the south-toward network route departures from Ningbo to Taizhou, Wenzhou, Fuzhou, Xiamen.

2.3 Existing problems

At present, the business scope of Ningbo Zhoushan port container sea-rail combined transportation concentrates in Zhejiang province and Jiangxi province, and extends to Jiangsu, Anhui, Hubei, Hunan, Sichuan and other regions. The network nodes are established densely in Zhejiang and Jiangxi provinces. In contrast, the construction nodes in other provinces lag behind relatively. In terms of transportation routes, it connects to national railway network by mainly relying on Xiaoyong line and Xiaoyong-Taizhou-Wenzhou line. Besides, the routes running to Xinjiang, Chengdu, Chongqing and Yunnan lack diversity. Therefore, the transport capacity and the development of sea-rail combined transportation network are greatly restricted. From the perspective of the layout of network routes, the construction of network nodes should be further improved and network routes also need to be optimized.

3. The optimization model

Assuming container goods need transferring to container inland depot through sea-rail combined transportation, the container sea-rail transportation network can be described as a diagraph $Q= \{N, L, W\}$, as shown in Fig.1. N constitutes the collection of the network nodes for container transportation; L constitutes the collection of container transportation routes; W is transportation cost and time weight of all routes. In the whole process of the transportation, any node has two modes of transportation (the dotted line represents the highway transportation and the solid line represents the railway transportation) to conduct transit transport. The corresponding transit cost and time will be produced by the mode of transportation at nodes.

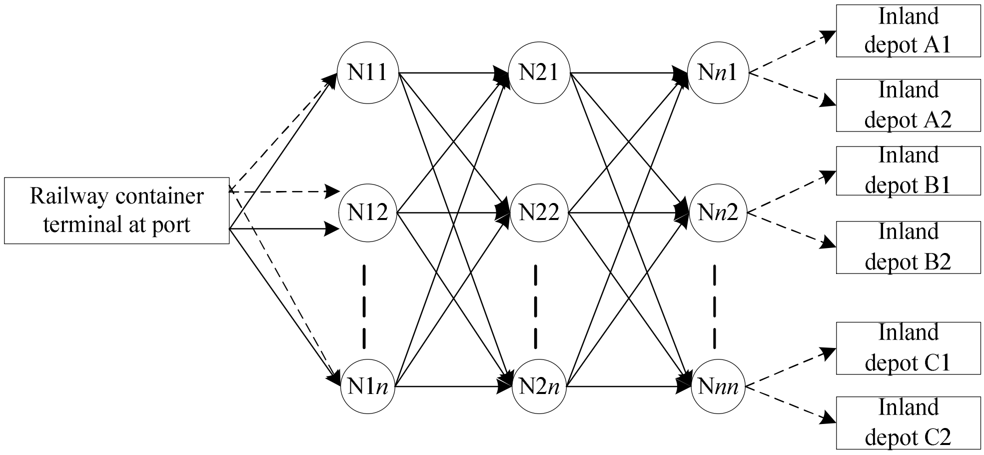

Fig.1. the digraph of the container sea-rail combined transportation network

3.1 Assumptions

(1) Given the number of network nodes of container sea-rail combined transportation;

(2) Assuming that transported goods are the same with shipper's own containers;

(3) The conversion between the modes of transportation at each node is possible, and the ability of reload meets all freight demands;

(4) Consideration is merely given to the transit cost and time in the process of reload. Meanwhile, other cost and delay time are ignored;

(5) The transportation cost is related to the type of goods, transport distance, transport mode. Moreover, there exists linear function relation between transport cost and distance;

(6) The freight traffic of railway container is fixed and interconnected at each node;

(7) In the process of transportation, all modes of transportation are operated at an average speed.

3.2 Relevant variables and parameters

O - the collection of the transport mode of container sea-rail combined transportation;

G - times of reload and transit;

α - the weight of transportation costs;

β - the weight of transportation time costs;

φ - the time-cost coefficient that is set 50 yuan/hour;

C_{ij}^{k} - the transportation cost that is caused by the selection of *k* transport mode from node *i* to node *j*, in which $i, j \in N$ and $k \in O$;

T_{ij}^{k} - the transportation time that is caused by the selection of k transport mode from node i to node j, in which $i, j \in N$ and $k \in O$;

c_{i}^{kl} - the transit cost that is caused by the selection of k transport mode from node i to node j, in which $i, j \in N$ and $k \in O$;

t_{i}^{kl} - the transit time that is caused by the selection of k transport mode from node i to node j, in which $i, j \in N$ and $k \in O$;

$$X_{ij}^{k} = \begin{cases} 1 & selection\ \ of\ \ k\ \ transport\ \ mode\ \ from\ \ node\ \ i\ \ to\ \ node\ \ j \\ 0 & no\ \ selection\ \ of\ \ k\ \ transport\ \ mode\ \ from\ \ node\ \ i\ \ to\ \ node\ \ j \end{cases}$$

$$Y_{i}^{kl} = \begin{cases} 1 & k\ \ transport\ \ mode\ \ is\ \ changed\ \ to\ \ l\ \ at\ \ node\ \ i \\ 0 & k\ \ transport\ \ mode\ \ is\ \ not\ \ changed\ \ to\ \ l\ \ at\ \ node\ \ i \end{cases}$$

3.3 Optimization model

Objective functions:

$$MinZ = \alpha Z_1 + \beta Z_2 \tag{1}$$

$$Z_1 = \sum_{k=1}^{O} \sum_{i=1, i \neq j}^{N} \sum_{j=1}^{N} C_{ij}^{k} \cdot X_{ij}^{k} + \sum_{i=1}^{N} \sum_{k=1, k \neq l}^{O} \sum_{l=1}^{O} c_{i}^{kl} \cdot Y_{i}^{kl} \tag{2}$$

$$Z_2 = \varphi(\sum_{k=1}^{O} \sum_{i=1, i \neq j}^{N} \sum_{j=1}^{N} T_{ij}^{k} \cdot X_{ij}^{k} + \sum_{i=1}^{N} \sum_{k=1, k \neq l}^{O} \sum_{l=1}^{O} t_{i}^{kl} \cdot Y_{i}^{kl}) \tag{3}$$

Formula (1) represents the minimum weight aggregation of both transportation cost and time. Formula (2) represents transportation cost, including transit cost of unloading and container truck transport at departures and destinations. Formula (3) represents transportation time cost, including the aggregation of transit time and the time cost coefficient, i.e. transit time cost.

Constraints:

$$\sum_{k \in O} X_{i,i+1}^{k} - \sum_{k \in O} X_{i-1,i}^{k} = 1 \qquad i \in N, k \in O \tag{4}$$

$$\sum_{k \in O} X_{i,i+1}^{k} - \sum_{k \in O} X_{i-1,i}^{k} = 0 \qquad i \in N, k \in O \tag{5}$$

$$\sum_{k \in O} X_{i,i+1}^{k} - \sum_{k \in O} X_{i-1,i}^{k} = \text{-}1 \qquad i \in N, k \in O \tag{6}$$

$$\sum_{k \in O} \sum_{l \in O} Y_{i}^{kl} \leq 1 \qquad i \in N、k, l \in O \tag{7}$$

$$X_{i-1,i}^{k} + X_{i,i+1}^{k} \geq 2Y_{i}^{kl} \qquad i \in N、k, l \in O \tag{8}$$

$$\alpha + \beta = 1 \tag{9}$$

Formula (4), formula (5) and formula (6) demonstrates that it is a complete route from the railway container center station at port to the container inland deport. Formula (7) represents that the reloading of container goods can only be conducted once at each network node. Formulas (8) represents that the transportation mode is changed from *k* mode to *l* mode at node *i*; the container goods are transported with *k* transport mode from node *i*-1 to *i* and with *l* transport mode from node *i* to node *i*+1. Formula (9) shows that the weight of transport cost and time cost in a sum of container transportation is 1.

3.4 Algorithm

Discrete particle swarm algorithm is featured by such merits as few parameters, memory function and fast convergence speed. The position of the particles is coded according to binary system and is discrete. The particle velocity indicates the probability of the change in particle position. Different from the standard algorithm of particle swarm optimization (pso) algorithm, this method requires that the position of each particle be denoted exclusively by "0" and "1". In other words, it transfers particle velocity v_{id} into the probability of particle position x_{id} being valued as "0" or "1" by introducing fuzzy function Sigmoid, which is closely related to particle velocity and decided by the value of v_{id}.

$$Sig(v_{id}^{t}) = \frac{1}{1+\exp(-v_{id}^{t})} \tag{10}$$

When the particle velocity v_{id}^{t} increases, the $Sig(v_{id}^{t})$ approaches 1; while the particle velocity v_{id}^{t} decreases, the $Sig(v_{id}^{t})$ tends to be 0. Therefore, the formula of the particle velocity and position is updated when it is *t*+1. Hereby, it is presented in the following.

$$v_{id}^{t+1} = wv_{id}^{t} + r_1 \cdot rand() \cdot (p_{id}^{t} - x_{id}^{t}) + r_2 \cdot rand() \cdot (p_{gd}^{t} - x_{id}^{t}) \tag{11}$$

$$x_{id}^{t+1} = \begin{cases} 1, if \qquad Sig(v_{id}^{t+1}) \ge rand() \\ 0, \qquad else \end{cases} \tag{12}$$

Here are more explanations of formula above. The *t* represents the iterative times. The *w* represents the inertia weight of articles moving. The *r*1 and *r*2 represents accelerated constants. The former exhibits the correlation between particles and individuals; while the latter indicates the relativity of particles to the group. Generally, the *r*1 often equals *r*2, and their values are usually between 0 and 4. The *rand ()* is a random number between 0 and 1.

In order to avoid extreme situations, the maximum value of particle velocity can be set $V_{\max}$ so that the particle velocity v_{id} is limited in a reasonable range from $-V_{\max}$ to $V_{\max}$. In this case, the value of particle position is likely to be 0 or 1, which is expected to achieve a satisfactory effect. In the discrete particle swarm optimization algorithm, a relatively small $V_{\max}$ can increase the possibility of particle position change, which facilitates to engage search on a wide scope. When $V_{\max}$ is 4, and vid ranges from -4 to 4, the possibility of particle position change will increases.

The discrete particle swarm optimization algorithm is completed with five steps in the following.

(1) Initializing the position and velocity of each particle in groups, and adopt the binary code;

(2) Decoding parameters, and then calculating the objective function value of each particle in groups according to the fitness function;

(3) Comparing the objective function value and the optimal value of each particle, and updating the individual optimal value and global optimal value;

(4) Calculating and updating each particle's speed and position according to the formula (11) and formula (12);

(5) Outputting the searched global optimal value as well as the objective function value, if termination conditions are met or iterations reach the maximum times; otherwise, returning to step (2).

4. Examples

According to the status of Ningbo Zhoushan port container sea-rail combined transportation network, the routes from Ningbo to Zhengzhou and from Ningbo to Chongqing will be optimized and the feasiability of the model and the algorithm will be testified in the following.

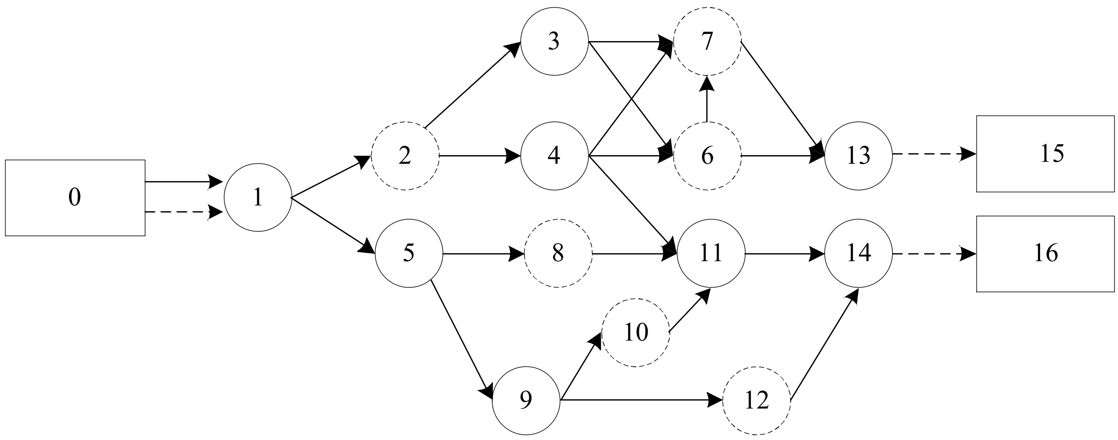

Fig.2. Ningbo Zhoushan port container sea-rail combined transportation networks

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 respectively stands for Ningbo Zhoushan port, Ningbo Northern station, Wuhu, Nanking, Hefei, Xiangtan, Fuyang, Xuzhou, Jiujiang, Zhuzhou, Yueyang, Wuchang, Huaihua, Zhengzhou, Chongqing, inland receiving station A and inland receiving station B in Fig.2, among which 2, 6, 7, 8, 10, 12 are alternative network nodes.

4.1 Basic data

Combined with the location of container sea-rail combined transportation network nodes, delivery fee of the containers and delivery distance of the network nodes can be known with delivery service model of 12306 official network. According to electric map, the delivery distance from Ningbo Zhoushan port to the railway of Ningbo Northern station and the highway of Ningbo Northern station is respectively 60 km and 50 km. Let's assume the highway delivery distance from railway container center to inland receiving station is 50 km under the condition that the average rate of railway container delivery and highway container delivery are 60 km per hour and 50 km per hour, then delivery fee and time of container sea-rail combined transportation network nodes could be calculated. Check Tab 1 and Tab 3. Assume that transferring fee of different delivery is the same and transferring time is different. The average transferring fee and time of the two ways are shown in Tab 2 with the information from material and cargo agent.

Tab 1 cargo freight rate of 20ft container sea-rail combined transportation

Transportation mode	Transportation basic price 1 (yuan / TEU)	Transportation basic price 2 (yuan / container-kilometer)
Railway[1]	500	2.025
Highway[2]	450 (within 10 kilometers)	24

Tab 2 transit cost and time of each transportation mode

Transportation mode	Railway (yuan/ hour)	Highway (yuan/ hour)	Waterway (yuan/ hour)
Railway	——	500/0. 72	500/1. 44
Highway	500/0. 72	——	500/1. 20
Waterway	500/1. 44	500/1. 20	——

Tab 3 transportation time, cost, distance between container sea-rail combined transportation network nodes

Departure to destination	Distance (kilometer)	Cost (yuan)	Time (hour)	Departure to destination	Distance (kilometer)	Cost (yuan)	Time (hour)
(0highway, 1)	52	1458	1. 04	(5, 9)	343	1194. 58	5. 72
(0railway, 1)	60	621. 50	1. 00	(6, 7)	235	975. 88	3. 92
(1, 2)	463	1437. 58	7. 72	(6, 13)	387	1283. 68	6. 45
(1, 5)	733	1984. 33	12. 22	(7, 13)	368	1245. 20	6. 13
(2, 3)	102	706. 55	1. 70	(8, 11)	261	1028. 53	4. 35

(2, 4)	183	870. 58	3. 05	(9, 10)	194	892. 85	3. 23
(3, 6)	400	1310. 00	6. 67	(9, 12)	435	1380. 88	7. 25
(3, 7)	361	1231. 03	6. 02	(10, 11)	208	921. 20	3. 47
(4, 6)	238	981. 95	3. 97	(11, 14)	1293	3118. 33	21. 55
(4, 7)	333	1174. 33	5. 55	(12, 14)	649	1814. 23	10. 82
(4, 11)	570	1654. 25	9. 50	(13, 15)	50	1410	1. 00
(5, 8)	180	864. 50	3. 00	(14, 16)	50	1410	1. 00

4.2 Algorithm and Analysis

Under MATLAB7.0 condition, the parameter of discrete particle swarm optimization algorithm should be set: the particle swarm n =40, the iterative times t =100, $r1$=$r2$ =1.5, w=0.8. When α =0.5, β =0.5, i.e. , cost factor is important as same as the time cost, the process of discrete particle swarm optimization algorithm is shown in Fig.3.

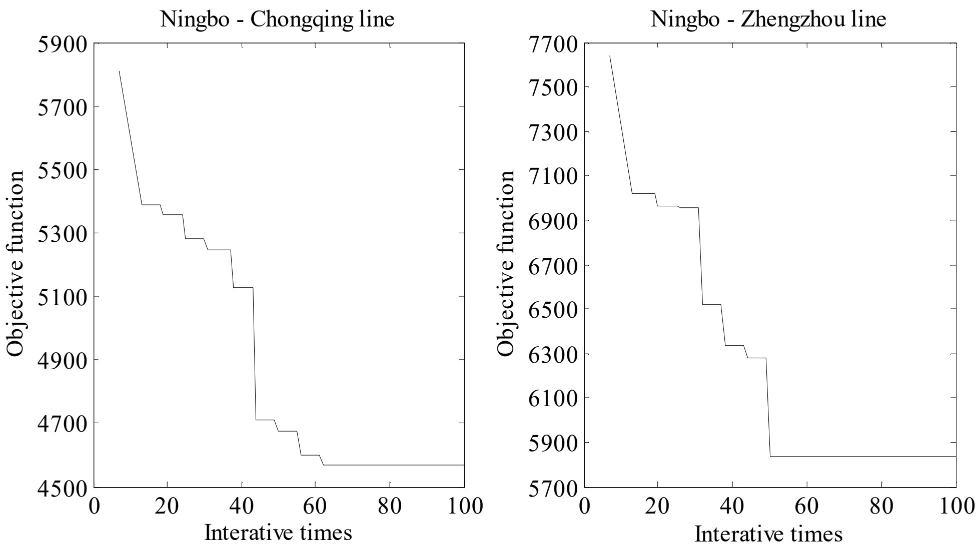

Fig.3. the process of discrete particle swarm optimization algorithm

Tab 4 the route and cost of Ningbo-Zhengzhou container sea-rail combined transportation

Transportation routes	Transportation cost (yuan / TEU)	Time cost (yuan / TEU)	Total cost (yuan / TEU)
(0highway, 1, 2, 3, 6, 13, 15)	8019. 31	1400. 5	4709. 91
(0highway, 1, 2, 3, 7, 13, 15)	7901. 86	1298. 5	4600. 18
(0highway, 1, 2, 4, 6, 13, 15)	7855. 29	1279. 5	4567. 40
(0highway, 1, 2, 4, 6, 7, 13, 15)	8792. 69	1459. 5	5126. 10
(0highway, 1, 2, 4, 7, 13, 15)	8009. 19	1344. 5	4676. 85
(0railway, 1, 2, 3, 6, 13, 15)	9355. 81	1424. 5	5390. 20
(0railway, 1, 2, 3, 7, 13, 15)	9238. 36	1324. 5	5281. 43
(0railway, 1, 2, 4, 6, 13, 15)	9191. 79	1305. 5	5248. 65
(0railway, 1, 2, 4, 6, 7, 13, 15)	10129. 19	1485. 5	5807. 35
(0railway, 1, 2, 4, 7, 13, 15)	9345. 69	1368. 5	5357. 10

Tab 5 the route and cost of Ningbo–Chongqing container sea-rail combined transportation

Transportation routes	Transportation cost (yuan / TEU)	Time cost (yuan / TEU)	Total cost (yuan / TEU)
(0highway, 1, 2, 4, 11, 14, 16)	10362.24	2311	6336.62
(0highway, 1, 5, 8, 11, 14, 16)	10277.19	2276	6276.60
(0highway, 1, 5, 9, 10, 11, 14, 16)	11392.79	2529.5	6961.15
(0highway, 1, 5, 9, 12, 14, 16)	9655.52	2020.5	5838.01
(0railway, 1, 2, 4, 11, 14, 16)	11698.74	2337	7017.87
(0railway, 1, 5, 8, 11, 14, 16)	11613.69	2302	6957.85
(0railway, 1, 5, 9, 10, 11, 14, 16)	12729.29	2555.5	7642.40
(0railway, 1, 5, 9, 12, 14, 16)	10992.02	2046.5	6519.26

Therefore, according to the calculated particle position, the two best transportation mode and route are worked out presented in Fig.4.

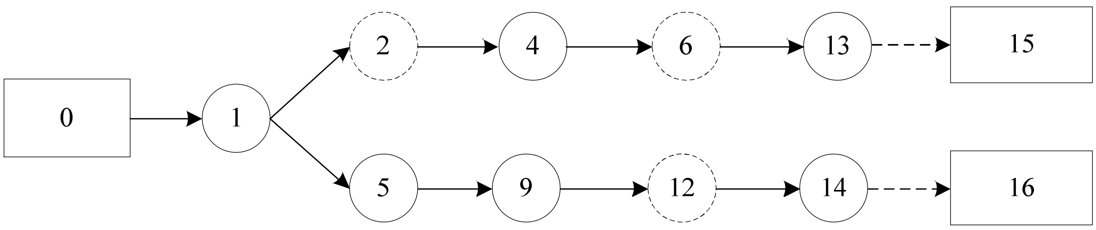

Fig.4. the best transportation mode and route

Regardless of the government premium policy, the best delivery route from Ningbo Zhoushan port to inland receiving station A starts from Ningbo Port (station), to Ningbo Northern station, Wuhu, Hefei, Fuyang and then Zhengzhou. Its distance is 1331 km and total cost is 4567.40 yuan with the cost on delivery and time 7855.29 yuan and 1279.5 yuan respectively. Compared to the route from Ningbo Port (station), to Ningbo Northern station, Nanking and Xuzhou, the total cost of one standard container in former way can be decreased by 0,72 percent. The best delivery route from Ningbo Zhoushan port to inland receiving station B crosses Ningbo Northern station, Xiangtang, Zhuzhou, Huaihua, Chongqing. Its distance is 2220 km and he total cost is 5838.01 yuan, with the cost on delivery and time 9655.52 yuan and 2020.5 yuan repectively. Compared to the route passing Jiujiang and Chongqing, the total cost in the former way can be decreased by 16.09 percent per TEU.

Conclusion

Given the limitation of transit time, cost and frequency, the optimization model with minimum total transportation cost (total cost of transportation cost and time) is established on the basis of the selection of network nodes and the optimization of transportation routes, which will be of great importance to the optimization of Ningbo Zhoushan container sea-rail combined transportation. Driven by “One Belt one Road” strategy, the international container sea-rail combined transportation will develop greatly. The further research will be studied on the international container sea-rail combined transportation lines that start from Ningbo to middle-Asia and European countries. The current railway plan will be taken into account to optimize transportation routes, aiming to promote the construction of Ningbo international container train lines.

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Footnote1: transportation cost by railway=basic price 1 + basic price 2 × transportation distance;
Footnote2: transportation cost by highway=basic price 1 (within 10 kilometers) + basic price 2 × (transportation distance -10).