Multi-modal Transportation Bi-objective Network Optimization Design based on Ideal Point Method

Yang Liu[1, *], Qun Yuan[1], Jie Liu[2], Xinghong Li[2], and Tingpeng Chen[3]

[1] School of Transport, Shanghai Maritime University, Shanghai, China

[2] College of Transportation and Logistics Engineering, Shandong Jiaotong University, Jinan, China

[3] Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai, China

*devoeyangl@163.com

Abstract

As an advanced transport organisation mode in the integrated transport system, multimodal transport is of great significance in adjusting the transport structure, reducing energy consumption, improving transport efficiency and promoting the synergistic development of various transport modes. In this paper, based on the existing multimodal transport theory, we consider the total cost and transport time as the optimisation objectives and the line transport capacity as the constraints, construct a multimodal transport network co-optimisation model, use the ideal point method to solve the model, and verify it through case studies. The results of the optimization are 14.3% lower in terms of total cost, indicating that the model established in this paper has good applicability. The model is thus a good theoretical support for the improvement of resource allocation efficiency of multimodal transport networks.

Keywords

Multimodal Transport; Network Planning and Design; Ideal Point Method.

---

1. Introduction

The development of multimodal transport can promote better integration of the inland economy into the international supply chain and provide a convenient environment for international trade; secondly, it also plays an important role in establishing new logistics corridors and paving new economic corridors. The multimodal transport network, as an important carrier for the transport of goods, plays an important role in the efficiency of multimodal transport. How to consider the characteristics of the properties of goods, the distribution of transport resources and other factors, to build a multimodal transport network that is compatible with demand and integrated with resources has become a hot issue for current research.

With the continuous enrichment of multimodal transport theory, many scholars have proposed various optimization models to study the problem. Sun et al. proposed an entropy-based TOPSIS decision model to study the multimodal transport corridor scheme from Ningbo-Zhoushan port to the southwest region[1]. Li Shuxia et al. designed a two-stage stochastic planning-based transit point location and sequential decision path planning to achieve an economical and efficient intermodal network design under the premise of uncertain cargo demand[2]. The application of the method is illustrated by numerical simulations of transport terminals based on given inbound and outbound logistics parameters and using the Dnipro River port as an example[3]. Liu Yanqiu et al. construct an optimal design model for multi-stage logistics networks considering carbon emission costs to solve the problem of selecting intermediate nodes and demand distribution in multi-stage logistics and distribution networks, in view of the characteristics of the multi-stage logistics and distribution network design problem[4]. Zhang et al. developed a multimodal transport distribution model to provide a basis for the design of transport networks for low-mobility people[5]. Ding explored the functions and operation of information systems in railways and ports, and established an electronic platform for the interconnection of information in multimodal stations by combining traditional information exchange models[6]. envisaged the future development of multimodal transport in three other regions such as the autonomous region of Žilina[7]. Fang et al. constructed an index system and measurement model for evaluating the intermodal synergy of container multimodal transport, taking the whole process of container multimodal transport as the research perspective[8]. Wang Chunyang considered factors such as logistics network facility constraints and carbon emissions, and established a multi-objective planning model to address the impact of facility construction, carbon tax rates and time delay costs on facility construction methods and network costs within logistics networks[9]. Xu et al. proposed a personalized multimodal transport service design based on SPSS (Smart Product Service System) to address the problems of poor coordination, inconvenient interchanges and difficult route planning of multiple transport modes[10]. Based on the big data of rail, road, waterway and air freight services, Wang used the logit model to conduct an in-depth study on the influencing factors and behavioral characteristics of multimodal transport. Based on the classification of cargo, the modelling and decision problems of multimodal network path design and optimisation are analysed[11].Zhou establishes a multimodal discrete network design considering traffic flow equilibrium constraint, investment constraint and expansion constraint for network operation cost and construction cost for minibus, bus and rail transport networks[12].Hong et al. consider the elasticity constraint of arrival time and introduce the soft time window factor into the multimodal transport path optimization study, established a dual-objective planning model for road minimization, and used a hybrid heuristic algorithm of minimum cost flow algorithm and simulated annealing algorithm to solve the model to achieve the path optimization model, and designed a suitable genetic algorithm to carry out the solution to obtain the optimal transportation scheme for multimodal transport[13].

Most of the research on the optimal design of multimodal networks at home and abroad has used genetic algorithms to solve the paths, and few papers have analysed the characteristics of the optimised networks, and even fewer have explicitly described the ways or structures by which the transport networks are described. In this paper, the genetic algorithm is improved to address these issues, and the total cost and time of the multimodal network is optimised using the ideal point method, taking into account carbon emissions as a condition for the cost of transporting goods according to China's carbon tax policy. Finally, the network topology model is constructed using the Space-P method to analyse the characteristics of the optimised network.

2. Model Construction

Due to the various forms of logistics transport, the use of a single mode of transport to meet the needs of O-D cities is not necessarily the best choice, in the case of meeting demand, the use of multimodal transport may be cheaper. Due to the high cost of air transport and the fact that direct flights do not necessarily exist between the two cities, this paper does not consider air transport as a way to transport goods. In the process of transport, the starting city must be connected to the end city and, depending on the situation, several transit cities can be chosen and at least one mode of transport can be chosen. With the objective of minimising transport costs and time, a multimodal network co-optimisation model is established.

2.1 Definition of Parameters

V Transportation node collection, $v \in V$;

K Among them, K1 is road transportation, K2 is railway transport, K3 is water transport;

m Cargo transportation;

d_{ijk} Indicates that transportation distance of the K species of transportation between node vi and node vj;

T_{ijk} Indicates that the transportation time of the transportation distance of the car cargo unit is used between node vi and node vj;

S_{ijk} Indicates that when the transportation method K is used between node vi and node vj, the unit distance emissions of the carbon dioxide;

S_{ikl} Indicates that the car carbon dioxide emissions generated by the K type transportation method is converted into the transportation method generated by the transportation method of L type;

C_{ijk} Indicates that the unit price of cargo transportation is used between node vi and node vj;

t_{ikl} Indicates that the conversion time of the K type transportation method is converted into the transportation method of the L -type transportation method. If there is no conversion, then $t_{ikl} = 0$;

X_{ijk} Indicates that whether there is a transportation method between the node vi and the node vj. If there is, then $X_{ijk}= 1$, otherwise it is 0;

Y_{ikl} Indicates that whether there is a transportation method at the node vi converting to the transportation method L. If the existence, then $Y_{ik} = 1$, otherwise it is 0;

C_{ik} Indicates that the transfer fee incurred by the transportation method at the node V_i is converted to the transportation method L. If there is no conversion, then $C_{ik} = 0$.

2.2 Optimization Model

$$\min C = \min \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} C_{ijk} d_{ij} x_{ijk} m + \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} c_{ikl} y_{ikl} m \tag{1}$$

$$\min S = \min \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} S_{ijk} d_{ij} x_{ijk} m + \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} s_{ikl} y_{ikl} m \tag{2}$$

$$C = \min C + \min S * x \tag{3}$$

$$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} T_{ijk} x_{ijk} + \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} t_{ikl} y_{ikl} \le T_0 \tag{4}$$

$$m \le m_{ijk} \qquad \text{i,j=1,2,…,n} \tag{5}$$

$$x_{ijk} y_{ikl} \in \{0,1\} \tag{6}$$

$$z = \sqrt{\left(c-c^*\right)^2 + \left(t-t^*\right)^2} \tag{7}$$

Formula (1) indicates the minimum transportation cost during transportation; formula (2) indicates the smallest carbon emissions during transportation; formula (3) represents total cost, X represents the carbon tax rate, the cost of the transportation process and the amount of carbon emissions are used in transportation process and the amount of carbon emissions. By the total cost of the carbon tax rate; formula (4) indicates that the goods must be reached within the specified time, and T0 represents the limit value of the transportation time of the goods; formula (5) indicates that in the process of cargo transportation, the volume of freight cannot exceed the maximum transport volume of the K type transportation method; formula (6) represents 0-1 variables; formula (7) indicates that the model is solved based on the minimum transportation cost c to get the c*, then the minimum solution model of the whole transportation time t is obtained to get t*, and the multi -target optimization problem is converted into a single target optimization problem.

2.3 Model Solution

Multi -type transportation network optimization design can be regarded as a special path optimization problem. At present, most of the research methods of such problems adopt genetic algorithms and simulation annealing algorithms, but as mentioned above, At the time, because the chromosomes were random crossing and mutation, there was a phenomenon that the waterway could not be carried out in a certain area but the final result was that the goods were delivered to the area through water transportation. The problem occurs. By calculating, the optimization results with the minimum total cost and the least transportation time, but because the genetic algorithm is prone to the phenomenon of local optimal, this article uses the ideal point method for further optimization. By selecting an ideal point that is closest to each optimal solution, and then comparing and evaluating the results obtained, the closer to the ideal point shows that the optimization is better. This article first uses the minimum of improving the genetic algorithm with the minimum of total cost c to get c*; and then to get t*at least at the minimum target of transport time t. Then use the ideal point method to obtain the formula (7), finally the small path of z is regarded as the best path.

3. Example Analysis

Company A is a company engaged in cargo transportation business, the company's transport network is mainly in the Yangtze River Delta and the surrounding areas, its water transport area is the Yangtze River, East China Sea waters, land transport mainly in Shanghai, Nanjing, Suzhou and Hangzhou and other areas. In recent years, China's logistics industry has developed rapidly and competition among third party logistics companies has become increasingly fierce. In this environment, Company A is committed to enhancing its competitiveness by shortening the logistics transportation time on the basis of ensuring the safe delivery of goods at low cost.

3.1 Node Data

Company A's urban nodes in the Yangtze River Delta and its surroundings are Nanjing, Zhenjiang, Wuxi, Changzhou, Kunshan, Huishan, Jiaxing, Jinhua, Hangzhou, Shaoxing, Ningbo, Suzhou, Shanghai, Nantong, and Yangzhou. The above node cities are numbered in order v1, v2, v3, v4, v5, v6, v7, v8, v9, v10, v11, v12, v13, v14, v15.

3.2 Other Cost Data

Table 1. Units of unit transfer costs and transfer emissions factor between different transportation methods

	Transit mode		
	Highway to Water	Highway to Railway	Railway to Water
Unit transfer fee (Yuan/TEU)	5	8	11
Average transfer time (h/TEU)	1.5	1.5	2
Transfer emissions factor (kg/TEU)	5.8	5.8	5.8

Checking the information to get the cost of road transportation is 0.34 yuan/(t*km); the cost of railway transportation is 0.12 yuan/(t*km); the cost of water transportation is 0.07 yuan/(t*km); The carbon emissions per unit were 0.027kg/(t*km), 0.006kg/(t*km), and 0.015kg/(t*km) respectively; the speed is 80km/h, 60km/h, 30km/h, respectively. The transfer costs and transfer emissions factors between different transportation methods are shown in the Table 1.

3.3 Model Solution Results

This article uses MATLAB for solution. Based on the existing O-D city connection relationship and transportation path of Company A. This article obtains 14 optimal paths after running MATLAB multiple times, such as the iteration convergence diagram from V8 to V13 as shown in Fig1.

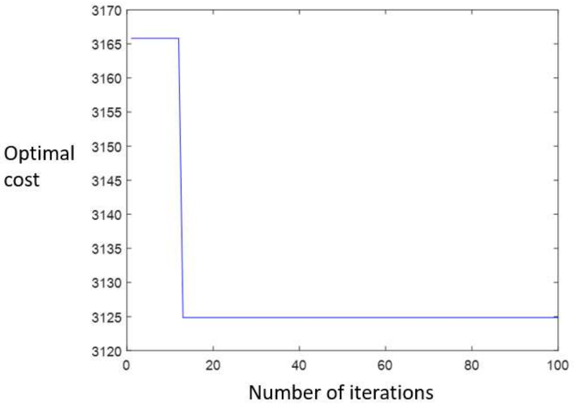

Fig. 1 V8 to V13 multimodal transport path iteration diagram

Table 2. The optimal path of multi -type transportation network

Serial number	Path	Transportation cost/yuan	Transfer cost /yuan	Carbon emissions /kg
1	Jinhua→Highway→Hangzhou→Highway→Jiaxing →Railway→Shanghai	2318	160	267
2	Jinhua→Highway→Suzhou	2108	0	167
3	Nanjing→Railway→Changzhou→Railway→KunShan →Railway→Shanghai	2046	0	36
4	Nanjing→Railway→Changzhou→Railway→Suzhou	1475	0	26
5	Nanjing→Waterway→Zhenjiang→Railway→Changzhou →Railway→Shanghai	1803	220	34
6	Yangzhou→Waterway→Zhenjiang→Railway→Suzhou	1139	220	23
7	Suzhou→Highway→Jiaxing→Highway→Hangzhou	1129	0	90
8	Nantong→Waterway→Shanghai→Highway→Ningbo	2336	100	273
9	Wuxi→Highway→Suzhou→Highway→Jiaxing	830	0	66
10	Shaoxing→Railway→Hangzhou→Highway→Nanjing	2380	160	290
11	Zhenjiang→Waterway→Wuxi→Highway→Jiaxing →Highway→Ningbo	2800	100	311
12	Huishan→Railway→Changzhou→Highway→Zhenjiang →Waterway→Yangzhou	812	260	282
13	Changzhou→Railway→Ningbo	715	0	61
14	Changzhou→Waterway→Hangzhou	1462	0	65
Total		23353	1220	1991

After iterative operations, the optimal path from V8 to V13 is to use highway transportation to Hangzhou from Jinhua, use road transportation to Jiaxing in Hangzhou, and use railway transportation to Shanghai in Jiaxing. Through the iteration of 15 O-D cities, the optimal path is obtained as shown in Table 2.

The total cost of solving the use of ideal points to obtain the optimal path of Company A is 24958 yuan, and the total time is 111.95 hours. In terms of total cost, the optimized transportation network was 4149.81 yuan less than that of Company A's initial use of only one mode of transportation to transport goods, a decrease of 14.3%; carbon dioxide emissions decreased by 309kg, a decrease of 15.7%. The optimization result obtained by the ideal point method can avoid the situation where the optimization occurs, and the optimized results have a large advantage compared to the original transportation lines of Company A at total cost, time, and carbon emissions. With the continuous development of Company A, the industrial cluster effect is formed, it can be foresee that the optimization efficiency of this multimodal connection network will be more obvious.

3.4 Company's Network Characteristics Analysis

This article uses the SPACE-P method to build a network topology model for optimized networks. The results are calculated through MATLAB. The result is shown in Table 3. Company A has a total of 15 nodes, 26 consecutive edges, the average degree of the network is 3.47, which means that each node in the network is connected to an average of 3.46 nodes.

Table 3. List of characteristics of Company A's multimodal transport network

Network feature value index	Number of nodes	Side	Average degree	Average path length	Cluster	Connect	Natural connection
Space-P	15	26	3.33	2.095	0.4	25	0.642

Fig 2 is distributed by Company A's network node. The nodes with the smallest network value of the network are Shaoxing, with a degree of value 1. The Shaoxing-Jiaxing Line is an important path for cargo transportation in the region. Most nodes in the network are greater than 1 .The degree value of 4 nodes is 2, accounting for 26% of the total number of network nodes, and the largest value is 7. The node is Shanghai. Shanghai is also the place and destination of most of the goods in Company A. This article uses the centrality of the node to dig out the more important nodes in the network. It obtains the highest level of Shanghai and Jiaxing. It is the two nodes with high importance in the network. The DCi of these two nodes are 0.5 and 0.428, respectively.

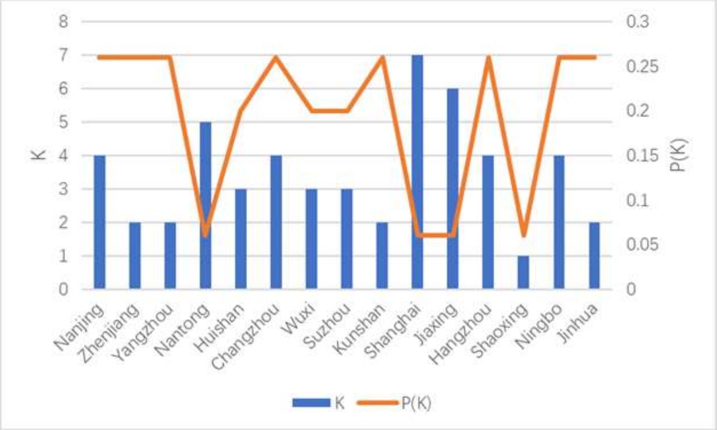

Fig. 2 The K and P(K) of each node

And there are 13 nodes in this network with non-zero node agglomeration coefficients. These nodes are connected to each other two by two, forming a triangular structure in the network, such as Nanjing, Nantong and Shanghai, and Hangzhou, Jinhua and Ningbo. These city nodes just show a standard triangular structure in the network. However, some of the nodes have a clustering coefficient of 0. The clustering coefficient of their stations is relatively low, indicating that the fault tolerance in this network is relatively poor, and if there is a problem with this line or city node, it will have a certain impact on the overall operation of the whole network.

4. Conclusion

In the multi -type transport network optimization, this article takes total costs and time as the optimization goal, and uses the transportation line carrier capacity and carbon dioxide emissions as the constraint. Under the results of the lowest total cost and the least time, the ideal point method is used. Solve the dual target into a single target problem to avoid the situation where the optimization results are avoided, making the optimization results more reliable.

Taking Company A as an example to verify and analyze the multi -type transport network, optimize the total cost of Company A in terms of total cost and carbon emissions, and the total cost of optimized has dropped by 14.3%.

Finally, this article analyzes the optimized traffic network. After obtaining the optimization, the average network is 3.33, the average path length is 2.095, and the natural connection is 0.642. Shanghai and Jiaxing have the highest degree centrality, and it is suggested that Company A can establish transit stations in Shanghai and Jiaxing in the future. The clustering coefficient of some nodes is 0, resulting in poor fault tolerance of the network, and once a problem occurs in this node, it will affect the entire network.

References

[1] Feng Sun, Xuefeng Wang, Lin Jin, Yeru Shi. Improvement of Rail-sea Multimodal Transport with Dry Port Construction: Case Study of Ningbo-Zhoushan Port[J]. Science Journal of Business and Management, 2017,5(2).

[2] Vitetta Antonino. Network Design Pro Blem for Risk Reduction in Transport System: A Models Specification[J]. International Journal of Transport Development and Integration,2022,6(3).

[3] Vitalii Naumov,Igor Taran,Yana Litvinova,Marek Bauer. Optimizing Resources of Multimodal Transport Terminal for Material Flow Service[J]. Sustainability,2020,12(16).

[4] Durán Micco, Javier. Transit network design: narrowing the gap between theory and practice[J]. 4OR, 2021(prepublish).

[5] Tao Zhang,Yang Yang,Gang Cheng,Minjie Jin. A Practical Traffic Assignment Model for Multimodal Transport System Considering Low-Mobility Groups[J]. Mathematics,2020,8(3).

[6] Ding Liqun. Multimodal transport information sharing platform with mixed time window constraints based on big data[J]. Journal of Cloud Computing,2020,9(1).

[7] Kramarz Marzena,Dohn Katarzyna,Przybylska Edyta,Knop Lilla. Scenarios for the Development of Multimodal Transport in the TRITIA Cross-Border Area[J]. Sustainability,2020,12(17).

[8] Xiaoping Fang,Zhang Ji,Zhiya Chen,Weiya Chen,Chao Cao,Jinrong Gan. Synergy Degree Evaluation of Container Multimodal Transport System[J]. Sustainability,2020,12(4).

[9] Hamilton George L.,Sanabria Hugo,Morcos Faruck,Kolimi Narendar,Krishnamohan Aishwarya. Sequence and Structure Based Approach for Automated FRET Network Design[J]. Biophysical Journal, 2021,120(3S1).

[10] Xu Gangyan,Zhang Ruibing,Xu Su Xiu,Kou Xiaofei,Qiu Xuan. Personalized Multimodal Travel Service Design for sustainable intercity transport[J]. Journal of Cleaner Production,2021,308.

[11] Wang Shuai,Fu Shaochuan. Path Design and Planning and Investment and Construction Mode of Multimodal Transport Network Based on Big Data Analysis[J]. Discrete Dynamics in Nature and Society, 2022,2022.

[12] Zhou Yaling,Cao Chengxuan,Feng Ziyan. Optimization of Multimodal Discrete Network Design Problems Based on Super Networks[J]. Applied Sciences,2021,11(21).

[13] Xiao Hong,Gong Hengjuan,Wang Xiaokun,Hang Bo. Routes Choice in the International Intermodal Networks under the Soft Time Window[J]. Wireless Communications and Mobile Computing,2022,2022.