

Structure Optimization Model of Comprehensive Transport Corridor Based on Resource Constraints

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Abstract: From the manager and the traveler's point of view, a bi-level programming model of structure optimization considering multi factors is proposed for comprehensive transportation corridor with parallel structure. In the higher level model, land resource consumption, upper model energy consumption and environmental emissions as indicators are selected as indexes to minimize the social resource cost. In the lower level model, the Mode-Path User Equilibrium model is selected for traffic distribution. To minimize the total travel cost of travelers, the supply and demand balance coefficient is selected as the channel response function and a model solution algorithm is designed based on genetic algorithm. At last, the proposed model is applied to Zhejiang Province Hangzhou Ningbo transportation corridor. The channel traffic demand is calculated for the planning year and the reasonable channel structure optimization program is given, which proves that the model is scientific and effective.

1. Introduction

Comprehensive transport corridor in the regional space system is an important part of comprehensive transport system, which composed of multiple transport modes, and connecting important urban nodes. The transport structure of comprehensive transport corridor involves the function orientation, allocation proportion, and restrictive relation of various transport modes^[1-3]. Literature^[4-6] studied the policy and effectiveness which impact comprehensive transport corridor transport structure transfer through considered the economic, environmental factors, investment, user demand and other factors. Literature^[7] analyzed the coupling mechanism of corridor traffic mode by using coupling theory and coordination theory. Literature^[8] realized the objective of minimizing transportation cost and maximizing transportation demand satisfaction under the compatibility constraint of cargo and transport mode. Literature^[9,10] used the improved Logit model realized the rational allocation of traffic mode in regional transport corridor. Therefore, most of the current research neglect the regularity and planned of freight transportation relative to passenger transportation^[8]. So, the corridor's structure optimization is a joint decision-making behavior of top-down, multi-level and hierarchical structure, which belongs to the typical principal and subordinate hierarch decision-making problem. Therefore, the idea of bi-level planning uses to construct structure optimization model of comprehensive transport corridor.

2. Structure Optimization Model of Comprehensive Transport Corridor

The structure of comprehensive transport corridor mainly refers to the spatial layout of the transport



modes or routes in the corridor. This paper studies two or more transport modes directly connect into a parallel structure corridor with better reliability or stability. The bi-level planning model of comprehensive transport corridor structure optimization involves two kinds of decisions, which are the upper system planner and the lower system user.

2.1 Upper Model

(1) Objective function index

1) Land resource consumption E_a . It can be expressed by site area of unit transport capacity. 2) Energy consumption E_b . It is expressed by the energy consumption per unit transport volume. 3) Environment pollutant emission E_c . It is expressed by the pollutant discharge per unit transport volume.

(2) Nondimensionalize index

In the process of converting multi-objective function into single-objective function, we need to nondimensionalize indexes to make these have different type's and dimension's objective function indexes comparability. Then normalize Land resource consumption E_a . The formula is as follows (1).

$$u_{aj} = \frac{E_{aj}}{\sum_j^n E_{aj}} \quad (1)$$

Where, u_{aj} is nondimensionalize value of land resources consumption of the j^{th} transport mode unit transport capacity. E_{aj} is the land resources consumption of the j^{th} transport mode unit transport capacity. n is the quantity of transport mode. Similarly, energy consumption E_b and environment pollutant emission E_c is normalized to obtain u_{bj} and u_{cj} .

(3) Model

In the comprehensive transport corridor system, H is defined as the set of section in the system. x_{h_j} is the traffic volume (passenger and freight) on the section h_j . s_{h_j} is the current transport capacity of section h_j . s'_{h_j} is the incremental transport capacity of section h_j . s'_{h_j} is decision variable ($h_j \in H$, j is transport mode on this section, take the value of 1, 2, 3 corresponding to the highway, railway, waterway). Therefore, in order to minimize resource, the upper model of the comprehensive transport corridor structure optimization is constructed according to the objective function index, index priority weight and nondimensionalize index. The formula is as follows (2).

$$\min z_1 = \min \sum_{h_j \in H} [(s_{h_j} + s'_{h_j}) \lambda_1 u_{aj} + x_{h_j} (\lambda_2 u_{bj} + \lambda_3 u_{cj})] \quad (2)$$

Where, λ_1 , λ_2 and λ_3 are respectively represents land resource consumption index, energy consumption index and environment pollutant emission index.

2.2 Lower Model

(1) "Mode-path" user equilibrium

Taking into account the salient feature of all transport modes' coordinated development in the comprehensive transport corridor, mode-path user equilibrium (MPUE) is constructed based on the traditional assignment model. It not only satisfies the requirements of corridor research but also improves the efficiency of the model. In the consideration of the influence of section transport capacity incremental, the impedance function is improved as shown in formula (3).

$$t(x_{h_j}, s'_{h_j}) = \begin{cases} t_{h_j}^0 [1 + \alpha (\frac{x_{h_j}}{s_{h_j} + s'_{h_j}})^\beta]; & j = 1 \\ t_{h_j}^0 + t_{jd} \frac{x_{h_j} - (s_{h_j} + s'_{h_j})}{s_{h_j} + s'_{h_j}}; & j = 2, 3 \end{cases} \quad (3)$$

Where, when $j = 1$, t_h^0 is the transportation time of section under the free flow. When $j = 2, 3$, t_h^0 is the current transportation time of railway and waterway. t_{jd} is the departure time interval in the

operation plan of railway and waterway; α and β are model parameters, generally taken $\alpha=0.15, \beta=4$.

(2) Model

In order to make travel become minimization objective, the MPUE of comprehensive transport corridor can be expressed as follows.

$$\min z_2 = \min \sum_{h_j \in H} \int_0^{x_{h_j}} t(w, s_{h_j}') dw \tag{4}$$

$$s.t. \begin{cases} \sum_k f_k^{OD} = q_{OD} \\ \sum_k f_k^{OD} \geq 0 \\ x_{h_j} = \sum_k f_k^{OD} \delta_{h_j,k}^{OD} \end{cases} \tag{5}$$

$$\delta_{h_j,k}^{OD} = \begin{cases} 1 & \text{Section } h_j \text{ on the "mode-path" } k \\ 0 & \text{other} \end{cases} \tag{6}$$

Where, K_{OD} is the set of all paths between OD. q_{OD} is demand volume (passenger or freight) between OD. f_k^{OD} is volume of the k^{th} "mode-path" between OD.

MPEU not only can obtain volume (passenger or freight) of each section, but also can obtain volume (passenger or freight) of each mode in comprehensive transport corridor by formula $f_j^{OD} = \sum_{h_j} x_{h_j}$.

2.3 Response Function of Upper and Lower Model

The transportation supply and demand of comprehensive transport corridor system should maintain the dynamic equilibrium state within a period of time. The supply-demand equilibrium degree can be reflected by the supply-demand equilibrium coefficient. Calculate supply-demand equilibrium coefficient ζ based on the adaptability of the supply and demand. The formula is as follows.

$$\zeta = \frac{G}{R} = \frac{\sum_{h_j} x_{h_j}}{\sum_{h_j} (s_{h_j} + s_{h_j}')} \tag{7}$$

Where, ζ is supply-demand equilibrium coefficient. If $\zeta=1$, then transport capacity and transport volume equilibrium. If $\zeta>1$, then there is a structural surplus of transport capacity, that is, a part of the transport capacity can't be fully utilized. If $\zeta<1$, it indicates that transport capacity supply shortage to satisfy the demand of comprehensive transport corridor. G is comprehensive transport corridor capacity total supply (transport capacity). R is comprehensive transport corridor capacity total demand (transport capacity).

Generally, when $\zeta=1.2$, comprehensive transport corridor transport capacity supply and transport volume demand are basically adaptation. When $\zeta=1$, the contradiction between supply and demand ease. When $\zeta=0.88$, the relation between supply and demand continue tension. In consideration of maximizing transport capacity and avoiding the supply shortage, taking $\zeta \in (1, 1.2)$.

3. Algorithm Solution

This study uses improved genetic algorithm to solve this problem. The specific steps are as follows.

Step one: Determine the dyeing individual's coding method. Utilize 0-1 Binary encoding, 1 means to choose this path, 0 is negative. Dyeing individual's coding method is as follows.

$$\underbrace{\underbrace{\underbrace{\sum_{i=1}^k n_i}_{n_1} \quad \underbrace{\quad}_{n_2} \quad \underbrace{\quad}_{n_k}}_{0 \dots 1 \dots 00 \dots 1 \dots 0 \dots 0 \dots 1 \dots 0}} \tag{8}$$

Every n_i variables is a chromosome structural unit that represents a pair of OD points' n_i paths. Then randomly select q_i variables from structural unit's n_i variable. These variables are coding "1" and

represent the alternative path. The others $n_i - q_i$ variables coding “0”, which represent they will not be chosen. All k units represent k pairs of OD point, and the total number of dyeing individual is $\sum_{i=1}^k n_i$.

Step two: Determine initial group. Randomly generate a chromosome that the position arrangement of 0 and 1 are not repeated. It forms the initial group that scale is a. It can ensure that "section transport volume \leq existing section transport capacity + the upper limit of transport capacity after section expansion ", or regenerate.

Step three: Determine suitability function. The reciprocal of the upper objective function is taken as the suitability function, that is, the lower the upper objective function value, the higher the dyeing individual suitability.

Step four: Selection. Each generation of group arrange according to the size of suitability degree, ranking first respect its individual performance is best. Then directly copy it into the next generation and rank first too. The other $a-1$ individuals in the next generation group need to be generated by betting wheel selection method based on the previous generation’s suitability.

Step five: Cross operation. In new group, in addition to the best individuals in the first place, the other $a-1$ individuals should be reorganized according to cross probability. First determine the cross probability P_c . In order to determine the parent of cross operation, repeat the following process. Generate a random number r from $[0,1]$, and if $r < P_c$, then select the individual as the parent. Afterward, cross calculate two parents and generate posterity. Then the accepted cross structural units in the parent 1 chromosome and the parent 2 chromosome are contradistinguished from left to right.

Step six: variation. First, select the individuals that accept variation according to probability P_v . Then select the structural units that accept variation in the individuals according to the probability P'_v . Randomly select the variable with coding “1”, and change it to “0”. Randomly select the variable with coding “0”, and change it to “1”.

4. Case study

This article selects “Hang-Yong-Zhou corridor (Hangzhou-Ningbo section)” as major research object. The structure diagram of transport corridor is shown in Figure 1, and the composition is shown in Table 1.

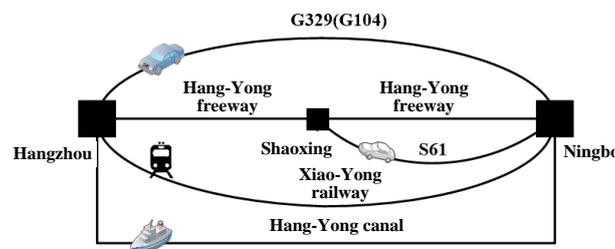


Figure 1 The Structure Diagram of Transport Corridor

Table 1 The Composition of Hang-Yong Corridor

Corridor name	Transport mode	Route name	Current situation
Hang-Yong corridor	Highway	Hang-Yong freeway	Freeway, 4 lanes
		104 national highway	Class I highway, 4 lanes
		329 national highway	Class I highway, 2 lanes
		S61 provincial highway	Class II highway, 4 lanes
			Class I highway, 4 lanes
		Class II highway, 4 lanes	
	Railway	Xiao-Yong railway	Double line class I
		Hu-Hang-Yong passenger	Underconstruction double

	dedicated line	line class I
Waterway	Hang-Yong canal	Class four

The following result is calculated by the formula, $S_{h_1}=198700$ t/y, $S_{h_2}=22480000$ t/y, $S_{h_3}=46050000$ t/y. It is known that the freight volume of the Hang-Yong-Zhou corridor $q_{OD}=420430000$ t/y in predict annual. Calculate to obtain $S'_{h_1}=287960000$ t/y, $S'_{h_2}=52000000$ t/y, $S'_{h_3}=35470000$ t/y according to “mode-path” assignment model. And $\xi=1.09$, fall into the interval (1, 1.2). Then through the analysis and comparison, gives adjustment suggestions about Hang-Yong-Zhou corridor (Hang-Yong section) traffic resources allocation. The results are shown in Table 2.

Table 2 Hang-Yong-Zhou Corridor (Hang-Yong section) Transport Mode Allocation Optimization

Name	Transport mode	Route name	Predict annual	
Hangzhou-Shaoxing-Ni ngbo section	Highway	Hang-Yong freeway	Freeway, 4 lanes	
		Hang-Shao-Yong double line	Freeway, 6 lanes	
		104 national highway	Class I highway, 6 lanes	
		329 national highway	Class I highway, 6 lanes	
		308 provincial highway	Class II highway, 4 lanes	
		S61 provincial highway	Class II highway, 4 lanes	
	Railway		Hang-Shao provincial highway	Class II highway, 4 lanes
			Xiao-Yong railway	Double line class I
			Hu-Hang-Yong passenger dedicated line (Hang-Yong section)	Double line class I
			Hang-Yong intercity railway	Double line class I
	Waterway	Hang-Yong canal	Class three	

5. Conclusion

(1) This paper mainly taking into account the maximization of manager’s resource utilization and minimization of traveler’s interest and supply-demand equilibrium. Then the bi-level planning model of comprehensive transport corridor structure optimization is established and the solution algorithm based on genetic algorithm is designed. (2) By applying the model to the Hang-Yong transport corridor, the corridor transport volume demand in planning annual was obtained. Then the reasonable corridor structure optimization scheme was given. It indicated the effectiveness of the model and algorithm. (3) In this paper, the model and solution are used for the transport corridor of parallel structure.

References

- [1] Fei Z R, Liu X M, Multi-factor and mathematical model for comprehensive transport channels layout in western China[J]. Journal of Beijing University of Technology, 2010, 36: 340-347.
- [2] Zhang J, Zhao P, Review of comprehensive transportation corridors planning[J]. Journal of Beijing Jiaotong University, 2010, 34: 142-147.
- [3] Li Y J, Application of fuzzy analytic hierarchy process in the selection of highway route program[C]. Second International Conference on Mechanic Automation and Control Engineering, 2011, 1985-1988.
- [4] Barfod M B, Salling K B, A new composite decision support framework for strategic and sustainable transport appraisals[J]. Transportation Research Part A Policy & Practice, 2015,

72: 1-15.

- [5] Truschkin E, Elbert R, Horizontal transshipment technologies as enablers of combined transport: Impact of transport policies on the modal split[J]. *Transportation Research Part A Policy & Practice*, 2013, 49: 91-109.
- [6] Wang X, Passenger transport contribution rate of multiple modes of transport in transport corridor[J]. *Journal of Railway Science & Engineering*, 2012, 9: 119-125.
- [7] Sun Q P, Jie G, Zou H B, The coupling mechanism and its coordination degree model of transport corridor[J]. *Journal of Chang'an University (Natural Science Edition)*, 2014, 34: 84-89.
- [8] Hua B, Tong Z, Architecture S O, Objective programming model for freight traffic-split rate in comprehensive transportation corridor[J]. *Journal of Chang'an University (Natural Science Edition)*, 2014, 34: 147-151.
- [9] Chen H, Zhang B, You Y S, Prediction model of transport sharing rates of the comprehensive transportation corridor[J]. *Social and Behavioral Sciences*, 2013, 96: 663-670.
- [10] Wang X Z, Zhao S C, Yan Z Z, Intercity transport mode split calculation method based on Rank Logit model[J]. *Journal of Transportation Systems Engineering & Information Technology*, 2012, 12: 137-143.