LOCATION MODEL OF TRANSPORT JUNCTION IN ECONOMIC CIRCLE IN CHINA AND ITS ALGORITHM

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ABSTRACT

Transport junction location problem has been a lot of relevant research at home and abroad, but the traditional location model rarely has taken into account the economic influence factor of the cites where the transport junction was located. On the basis of analyzing the internal relation between economic development of cities and transport junction in the economic circle, this paper introduced the six factors that influenced economic development level of cities in the economic circle and developed a Bi-Level programming modal with the minimization of the transportation costs and the junction construction costs, the maximization of economic influence of the cities where the junction was located, and considering the traffic equilibrium on the roads in economic circle. Hybrid niche genetic simulated annealing algorithm was proposed for solving the model quickly, which was programmable and practicability. Thereafter, the validity and practicability of the proposed model were demonstrated by the example of transport junction location in the economic circle of Yangtze River Delta.

Keywords: economic circle，transport junction，location model，niche genetic simulated annealing algorithm

1. INTRODUCTION

Transport junction is a very important component in the transport system, which plays a critical role in improving the function of the transport system and promoting the development of the cities. The rational location of transport junction not only saves transportation costs, but also largely accelerates the regional economic development.

At present, the location of transport junction is a hot issue being widely researched at home and abroad. At abroad, it mainly belongs to facilities location problem. A. Klose and A. Drexl divided the facility location problem into several categories by studying it in depth, and summarized linear location model, network-based location model, mixed integer programming model and their applications. J. Harkness and C. ReVelle studied the facility location model of incremental production costs. Esnaf analyzed different geographical location using fuzzy clustering analysis method to select the center of the clustering analysis as the candidate location for the facility, and then identified the point with optimal transportation costs as the location using gravity model. Racunica and Wynter took into account the economical factors due to the expansion of business scale in studying on transportation junction location problem.

In China, Zhang Sanxing established respectively single-point discrete location model, alternative location-allocation model as well as the junction location model considering qualitative factors, of which the common place is to take the point with minimum total costs of the transportation costs traveling between several pre-determined districts and the junction and the junction construction costs as the junction location. Liu Canqi proposed a transport junction location model based on traffic equilibrium. Yan Lijun et al. established the junction location model based on super transport network and OD trip matrix, of which the common place is using user equilibrium assignment model as the lower model. Wang Laijun et al. established a kind of mathematical facility location model with restricted capacity which can reflect the reality, and gave out the steps to solve it using genetic algorithm.

Seen from above, gravity method, differential method and transportation benefit-cost analysis method are mainly used in junction location planning. While optimization methods for junction location problem such as linear programming, integer programming and mixed-integer programming also appeared with the application of operations research in transport field.

With the formation of economic circle, transport junction location problem is becoming increasingly important for the economic development within the circle. However, researches on transport junction location in economic circle at home and abroad are still relatively insufficient currently. This article is aimed to establish a transport junction location model in economic circle by considering its characteristics at macro-level, and taking the minimization of the transportation costs and junction construction costs as well as the maximization of economic influence of the cities where the junction located as the goal, then to solve the model by using niche-based genetic annealing algorithm on the NP-hard problem.

2. CHARACTERISTICS OF TRANSPORT JUNCTION LOCATION IN ECONOMIC CIRCLE

Economic circle is an economic organization entity formed within a certain region, is a geographical combination of the distribution of productive forces, and is also a geographical industrial configuration circle with internal relations. The GDP in economic circle often occupies a large proportion of the total GDP in national economy. The Yangtze River Delta, the Pearl River Delta, and the region of Beijing-Tianjin-Hebei are three major economic circles formed in China at present.

Regional economic development must rely on market economy which has the prominent features of socialized exchange, collaboration and opening up at a large scale. That requires strengthened communication among the various regions and industries. Only through increasingly frequent exchanges and communications between regions, cities and rural areas with the flow of people, logistics, information, capital and technologies, could regional economy have a better development to prosperity. The development of transport network with high-density and large-capacity as well as rationally distributed transport junctions in economic circles where there are abundant human and capital resources would not only make the above exchanges and communications more convenient and rapid, but also significantly reduce the operating costs (including transportation costs of goods and enterprises purchasing costs of raw materials etc.) in market economy, effectively form various regions into a relatively well and influential economic entity.

As an important transport facility, transport junction in economic circle is mostly located at the combining district of several transportation modes or the intersections of several transportation routes, which makes it becoming the collection and distribution center of logistics, people and traffic within the regional road network and easy to achieve synergies between various transportation modes. Thus a large number of passengers and cargos are always gathered here. Due to the superior location and convenient transport conditions, a number of influential markets are always formed around the transport junction, which could strongly promote the formation of the industrial and agricultural layout and the development of commercial trade, and greatly enhance the economic influence of the cities where the transport junction located. On the other hand, the substantial promotion of economic influence of the cities will in turn attract more people, materials and capital, and thus further promote the economic development of the cities. Therefore, rational distribution of the transport junction plays an important role in the economic development of economic circles.

When the construction fund is limited for junction, transport junction location in economic circle should not only meet the optimization of the transportation costs, but also take into account various construction costs of transport junctions in different cities, as well as the economic influence of the city where the transport junction located, to meet the special optimization of the regional economic development. There are many factors that will decide the economic attraction of the city where the junction locates, such as the population, GDP, the ratio of floating population, the level of urbanization and the proportion of tertiary industry. However, as long as the building of a transport junction, more traffic will be attracted while the economic influence of the city being promoted, which may cause the congestion on the surrounding roads and the increase of the transportation costs.

According to the above characteristics, two aspects should be taken into account when selecting the transport junction location in economic circle: one is to minimize the transportation costs between transport junctions and the construction costs of the junction, as well as to maximize the economic influence of the transport junction; the other is to meet the equilibrium of traffic flow on the road network, and prevent the transportation costs from increasing caused by traffic congestion.

3. BILEVEL PROGRAMMING MODELS

In this paper, the above problem is described through the establishment of a Bi-level mathematical programming model, with the upper model optimizing transportation costs, construction costs and economic influence, and the lower model finding the traffic volume on the roads under equilibrium condition in the economic circle.

3.1 The upper model

Assume that there are all together n cities in the objective region, m large junctions are going to be built, only one large junction for each city, $n > m$. Passengers and cargos are traveling from the origin o to the destination d, passing the nearest junction i and another junction j. Thus the model for the transportation costs could be described as:

$$\min G = \sum_{o=1}^{n}\sum_{i=1}^{m} c_{oi}\cdot x_{oi} + \eta\sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} t_a(x_{ij}) + \sum_{j=1}^{m}\sum_{d=1}^{n} c_{jd}\cdot x_{jd} + \sum_{i=1}^{m}\sum_{j=1}^{m}(c_i + c_j)x_{ij} \qquad (1)$$

The constraint equation is:

$$\sum_{o=1}^{p}\sum_{i=1}^{m} x_{oi} + \sum_{j=1}^{n}\sum_{d=1}^{q} x_{id} = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}$$

Where x_{ij} is the traffic volume from junction i to junction j; x_{oi} is the traffic volume from o to junction i; x_{jd} is the traffic volume from junction j to the destination d; c_{oi} and c_{jd} are respectively the transportation costs travelling from the origin to the candidate junction and from the candidate junction to the destination; c_i and c_j are respectively the per unit transit costs of junction i and j; $t_a(x_{ij})$ is the travel time function between junction i and j on road section a, which can be turned into transportation costs with a dimensionless conversion factor η.

To simplify the computation, the transportation costs between the cities in the economic circle rather than transportation costs inside the city will be considered in this paper. That is to say, eliminate the constraint equation in Equation (1) by taking the city where the junction located as the origin and destination of the passengers and cargos. Thus the transportation costs model is simplified as follows:

$$\min G = \eta\sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} t_a(x_{ij}) + \sum_{i=1}^{m}\sum_{j=1}^{n}(c_i + c_j)x_{ij} \qquad (2)$$

The construction of transport junction needs a large amount of capital investment, while the costs on demolition and grants of the transport junction accounted for a large proportion of the expenditure on construction costs besides the costs on construction materials. So the factor of land price in the city where the transport junction located should be taken into account. The construction costs model of the transport junction is established by introducing a land transfer price coefficient h_{ir} as follows:

$$\min \mathrm{T} = \sum_{i=1}^{m}\sum_{r=1}^{n} b_i z_{ir} h_{ir} \qquad (3)$$

Where b_i the expected construction is costs of junction i; h_{ir} is the land transfer price coefficient for city r;

$$z_{ir} = \begin{cases} 1, \text{junction i located at city r} \\ 0, \text{or else} \end{cases}.$$

Generally speaking, the greater the economic influence of a city is, the faster its economic development will be. Correspondingly, the level of urbanization of the city will be higher, the gross national product and the proportion of tertiary industry will increase, which also increases the attraction to the floating population. And the economic activities and population migrations will in turn surge the traffic volume of the city. Therefore, traffic volume is another important factor that reflects the dynamics of urban economic development, the increase of total traffic volume demonstrates the improvement of economic influence of a city. Considering the above 6 factors that effect the economic influence of the city, the optimization model to maximize the economic influence of the city in the economic circle is established as follows:

$$\max I = \sum_{i=1}^{m}\sum_{r=1}^{n} w_r(x_{ir}) \qquad (4)$$

$$w_r(x_{ir}) = x_{ir} \cdot v_r \cdot u_r \cdot \alpha_r \cdot \beta_r \cdot \tau_r \cdot \sigma$$

Where $w_r(x_{ir})$ is the economic influence model of city r in the economic circle, x_{ir} is the total traffic volume from junction i to city r; v_r is the population of city r; u_r is the GNP of city r; α_r is the level of urbanization of city r; β_r is the proportion of floating population in city r; τ_r is the proportion of tertiary industry in city r; σ is the dimensionless conversion factor.

The above (2) (3) (4) optimization objective equations were combined into one multi-objective optimization problem, namely, the upper model of transport junction location in the economic circle as follows:

$$\min F = (\eta\sum_{i=1}^{m}\sum_{j=1}^{m} x_{ij} t_a(x_{ij}) + \sum_{i=1}^{m}\sum_{j=1}^{m}(c_i + c_j)x_{ij} + \sum_{i=1}^{m}\sum_{r=1}^{n} b_{ir} z_{ir} h_{ir}) / \sum_{i=1}^{m}\sum_{r=1}^{n} w_r(x_{ir}) \qquad (5)$$

Where, F is the overall objective optimization value of the transportation costs inside the economic circle, the construction costs of the transport junction and the economic influence of the city in the economic circle.

3.2 The lower model

The lower model is typical mathematical programming problem of user equilibrium, which is described as:

$$\min F(x) = \sum_{a\in A}\int_0^{x_a} t_a(w)dw \qquad (6)$$

$$s.t. \quad \sum_k f_k^{rs} = q_{rs} \qquad \forall \gamma, s$$

$$x_a = \sum_{r,s}\sum_k f_k^{rs} \cdot \delta_{a,k}^{rs} \qquad \forall a$$

$$f_k^{rs} \geq 0, \qquad \forall \gamma, s \ \ \forall k$$

Where the travel time formula proposed by the U.S. Roads Bureau (BPR) is used as the impedance function of the road sections:

$$t_a = t_a^0\left[1 + \theta\left[\frac{f_a}{c_a^{'}}\right]^{\varphi}\right] \qquad (7)$$

Where t_a^0 is the impedance when the traffic volume is zero, that is the free travel time when the volume on the road section is zero, the travel time corresponding to the design speed of the road section could be used; $c_a^{'}$ is the actual capacity of road section a ,namely, the capacity constraint; θ and φ are parameters of the model, generally, θ=0.15, φ=4.0.

4. ALGORITHM

The lower model is typical user equilibrium traffic assignment optimization model. To solve traffic assignment problem, searching algorithms based on road section and road path are usually used. Generally speaking, path-based traffic assignment algorithm, mainly including disaggregate simple type decomposition and gradient projection algorithm, is most widely used for providing more information about traffic volume and being more efficient. In this paper, the lower model is solved using gradient projection algorithm according to reference of Huang Haijun. The initial solution of the lower model is used into the upper model, making the upper programming problem into ordinary optimization problem. After obtaining the new optimal solution with optimization method, the lower programming problem is resolved according to the distribution of the junctions, to obtain new traffic volume on road sections. Through iterative calculation, the optimal value of this Bi-level programming model is obtained finally. Bi-level programming problem is a kind of system optimization problem with two-level ladder structure. The nature of non-convex and non-everywhere differentiability makes it very difficult to solve. Niche-based genetic annealing algorithm only needs to know the information of the value of the objective function, having nothing to do with whether the objective function is continuous and differentiable or not, thus is fast to convergent and easy to obtain the optimal solution.

Genetic algorithm is a technology simulated the principle of survival of the fittest in the biosphere, which is a way using in individual's mating (crossover) in the cluster. Although it increased the capability to search for the solution space of the problem, it lacked considerations about the potential effect of mating (the quality of the offspring). Problems may be resulted in such as unsatisfactory on the effectiveness of the mating and the efficiency of optimization. In nature, creatures always tend to live together with creatures that have similar characteristics and biological traits to themselves, and mate and reproduce with homogeneous. In biology, a particular environment and the clusters surviving in this environment is known as the niche. In order to solve the above problems, introducing niche technology into the basic genetic algorithm, considering the certain condition that individuals are not entirely mating randomly, has been proved to be an effective method. Simulated annealing algorithm is a kind of random searching method for solving combinatorial optimization problems. It has relatively wide range of adaptability because a certain appropriate random factors are introduced in the strategy to search for the optimal solution, and no special constraints are needed in the objective function.

The steps of niche-based genetic annealing algorithm are as follows:

Step1: Initialization. To evolve the algebra counter $u \leftarrow 1$, the temperature cooling coefficient is C, the initial annealing temperature is $t \leftarrow t_0$. Initialize the cluster by random method, and calculate the adaptability of the cluster; M initial individuals are randomly generated to form the initial cluster $p_0\left(u\right)$, and the adaptability for each individual is calculated as $F_i\left(i=1,2,\cdots,M\right)$.

Step2: To sort the individuals in descending order according to their adaptability, and to memorize the first N individuals $(N < M)$.

Step3: Selective operation. $p_1(u)$ is obtained by carrying out a proportional selective operation to the cluster $p_0(u)$.

Step4: Crossover operation. $p_2(t)$ is obtained by carrying out a single-point crossover operation to the selected group of individuals $p_1(t)$. The offspring C_1 and C_2 are generated by mutation operator using crossover operation from the origin P_1 and P_2, and then calculate their adaptabilities. If $F_c > F_p$, $i = 1, 2$, then replace P_i with C_i; Otherwise, maintain P_i with the probability of $\exp\left(\frac{F_{C_i} - F_{P_i}}{t}\right)$.

Step5: Mutation operation. $p_3(t)$ is obtained by carrying out uniform mutation operation to $p_2(t)$.

Step6: Niche-out operation. Combine the obtained M individuals and the initially memorized N individuals together, to obtain a new cluster of $M + N$ individuals; calculate the Hamming distance between every two individuals x_i and x_j according to the following formula to the $M + N$ individuals:

$$\|X_i - X_j\| = \sqrt{\sum_{k=1}^{T} (x_{ik} - x_{jk})^2}$$

Where $i = 1, 2, \cdots, M + N - 1$, $j = i + 1, \cdots, M + N$; T is the number of decision variables to solve the problem.

When $\|X_i - X_j\| < L$ (L is the minimum Hamming distance, that is, the distance parameter between the pre-specified niches), compare the individuals and their adaptabilities, impose penalty function: $F_{\min(x_i, x_j)} = \mathrm{P}$ to the individuals with lower adaptability, where P is a very small positive number.

Step7: To sort the $M + N$ individuals in descending order according to the new adaptabilities, and to memorize the first N individuals.

Step8: Judgment of the terminal condition. If $t > t_{final}$, where t_{final} is the terminal temperature, then update the temperature with $t \leftarrow Ct$ and $u \leftarrow u + 1$, and use the sorted M individuals in step7 as the new generation of cluster $p_0(u)$, and then go back to step3; otherwise, return to the optimal solution and end the algorithm .

5 . A NUMERICAL EXAMPLE

In this paper, the economic circle of Yangtze River Delta is taken as the object of the study. In order to facilitate verifying the model, the road network in the economic circle of Yangtze River Delta is simplified as shown in Figure 1. The road network contains 14 nodes (that is, 14 cities in the economic circle), and select 4 out of the 14 nodes to build transport junctions.

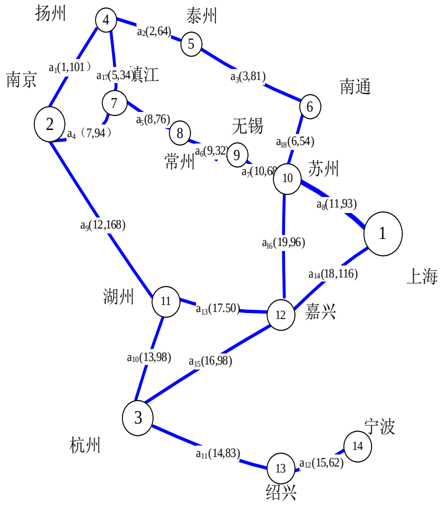

Figure 1 –Transport network diagram in the economic circle of Yangtze River Delta

5.1 Input data and parameter settings

The 14 cities in the economic circle are numbered as shown in Figure 1, all cities are connected to each other by 19 lines, the distances between every two cities are as shown in the figure. For example, （18， 116） shows the route number and distance between Shanghai and Jiaxing, where 18 is the route number, and 116Km is the distance between the two cities. According to the Statistical Yearbook, the economic influence factor for each city in the economic circle of Yangtze River Delta is as shown in Table 1.

According to the road network statistics of Yangtze River Delta, the current OD traffic volume on the road network in the economic circle of Yangtze River Delta can be derived reversely from the observed traffic volume on road sections as shown in Table 2. Assume that the design speed on each road section is 50km / h, the capacity $c_a^{'}$ are all 5000pcu / h, parameters η and σ are both 0.1, the transportation cost between the two junctions c_i is 2, the expected construction cost of the junction b_i is 10,000, the land transfer price coefficient of the city h_{ir} is largely related to the urbanization level of the city, the land price is usually higher in the city with a higher urbanization level, so h_{ir} is simply calculated as multiply standard value 1 by the urbanization level of the city α_r .

5.2 The output

According to the steps of the niche-based genetic annealing algorithm, Matlab is used to program and simulate in this paper. Assume the size of the cluster is 20, the mutation probability is 0.3, the initial temperature is 500, the terminal temperature is 100, and the temperature cooling coefficient is 0.9. Niche-based genetic annealing algorithm is used to optimized solve the model, the optimal solution F= 878.57 can be obtained only taking 56 times of iteration and 4.6s of time. In order to test the efficiency of the algorithm, normal genetic algorithm is also adopted to solve the problem in this paper. In this way, the optimal value is obtained by taking 93 times of iteration and 7.9s of time. Therefore, niche-based genetic annealing algorithm is much faster than normal genetic algorithm. If there are a large number of transport nodes and road sections in the example, the advantage of niche-based genetic annealing algorithm will be more apparent. The result is obtained using the above model as $Z_{11}=1$， $Z_{22}=1$， $Z_{33}=1$， $Z_{49}=1$, that is, the optimal solution is obtained when selecting Shanghai, Nanjing, Hangzhou and Wuxi as the transport junction locations in the economic circle, the traffic volume on each road section are as shown in Table 3. Due to the consideration of the economic influence of the city where the junction located, even if the transportation costs and construction costs are not the minimum, the total costs F will always be minimum at the optimal solution.

Table I –The Data of the cities in the economic circle of Yangtze River Delta

City	Population (Million)	GDP (Billion)	Floating population	Urbanization level	The third industry	City	Population (Million)	GDP (Billion)	Floating population	Urbanization level	The third industry
Shanghai	13.7886	1200.1	24.6%	88.7%	51.9%	Taizhou	5.0070	120.2	3.7%	45.3%	33.2%
Nanjing	6.1720	327.5	40.6%	76.3%	48.4%	Nantong	7.6613	211.2	6.8%	45.8%	35.8%
Suzhou	6.2400	570.0	93.7%	65%	34.6%	Hangzhou	6.7235	410.4	42%	68.1%	45.7%
Wuxi	4.6174	385.8	47.5%	67%	40.1%	Jiaxing	3.3681	158.5	48.7%	57.2%	33.9%
Changzhou	3.5740	188.0	41.8%	60.4%	38.1%	Huzhou	2.5780	89.6	21.4%	44.1%	35.4%
Zhenjiang	2.6878	121.3	12.9%	59.1%	38.9%	Ningbo	5.6460	343.3	37.7%	62.5%	40.5%
Yangzhou	4.5925	131.1	9.6%	48.3%	37.8%	Shaoxing	4.3624	197.1	19.7%	58.84%	34.2%

Table 2 –The status OD data in the economic circle of Yangtze River Delta Units: PCU

OD	Shanghai	Nanjing	Hangzhou	Yangzhou	Zhenjiang	Taizhou	Changzhou	Wuxi	Nantong	Suzhou	Huzhou	Jiaxing	Shaoxing	Ningbo
Shanghai	0	789	4119	1193	2629	3163	4667	3959	3175	458	600	1500	352	452
Nanjing	767	0	703	1899	5257	233	657	1850	2375	324	398	1179	539	1931
Hangzhou	4157	2584	0	1931	918	2009	2213	3356	1716	830	2413	3560	860	1213
Yangzhou	1038	1517	2219	0	1766	628	1344	3534	1452	312	621	1545	567	445
Zhenjiang	2131	5644	819	1412	0	1006	3781	8516	10608	3131	2047	1996	3683	2893
Taizhou	2504	2403	2223	2698	1125	0	3315	4055	4632	479	472	1653	463	364
Changzhou	4430	1398	679	1935	3840	3646	0	4176	2256	551	1422	2816	982	693
Wuxi	3259	1994	808	4462	11487	2002	8078	0	3797	469	574	3046	420	366
Nantong	2361	3903	796	1974	12050	1268	6115	3102	0	501	1769	2289	1362	546
Suzhou	458	324	830	312	3120	479	551	469	501	0	487	2198	1095	378
Huzhou	600	398	2413	621	1998	472	1422	574	1769	487	0	1461	798	511
Jiaxing	1426	1179	3662	1545	1886	2123	2816	3046	2289	2198	1461	0	1576	2590
Shaoxing	352	539	860	567	3661	463	982	420	1362	1095	798	1576	0	862
Ningbo	461	1931	1213	445	2742	357	693	366	546	378	516	2560	836	0

Table 3 –The traffic flow of all the roads in optimal solution Units: PCU

section	1	2	3	4	5	6	7	8	9
flow	8276	4150	3416	5667	6961	12254	6899	25658	1200
section	10	11	12	13	14	15	16	17	18
flow	2922	3152	2190	1022	5635	5180	1092	4232	6278

6. CONCLUSIONS

In order to promote the economic development in economic circle, this paper combined the economic influence of the city and the traditional transport junction location model, and took traffic equilibrium on road network into consideration, proposed the transport junction location model in economic circle. This model took six factors that affect the economic development level of the city in the economic circle into comprehensive consideration, made a close combination of transport junction location and economic development of the city in the economic circle together. Finally, niche-based genetic annealing algorithm which designed for this model was tested to be easy programming and fast to obtain the optimized value. However, the assumptions and related parameters in this paper are set idealized, so some value of the parameters need to be further corrected to fit the actual data.

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