Site Selection Study of Urban Underground Logistics System Nodes

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Abstract

In order to study the node location problem of urban underground logistics system, we combine the research results of underground logistics system at home and abroad, consider the service radius and service capacity of nodes and other factors, establish a two-layer planning model with the minimum number of underground logistics nodes and the minimum transit rate of primary nodes as the optimization objective, and carry out optimization solution by genetic algorithm, and take a region in China as an example to finally determine the number and location of underground logistics nodes. The research results show that the model and algorithm used in this paper are effective and feasible for the underground logistics node location problem, and the locations of three primary underground logistics nodes and 16 secondary underground logistics nodes are obtained by Matlab solution, and the average transit rate of primary nodes is 48.84%.

Keywords

Underground Logistics; Node Siting; Node Transit Rate; Two-level Planning; Genetic Algorithm.

1. Introduction

In recent years, urban traffic congestion has become increasingly serious in China, especially in large cities, where traffic congestion has become normalized and regionalized [1], and this has led to a series of "urban diseases" such as frequent traffic accidents and increased environmental pollution. Governments at all levels in China have taken various measures, such as building viaducts, increasing road lengths, widening existing roads, and building bus rapid transit corridors, but the traditional model of expanding road capacity alone has proven to be a drop in the bucket for the rapid growth of urban traffic demand. Therefore, many experts at home and abroad have turned their attention to the development and utilization of underground space, and a new idea to solve traffic congestion has emerged - the construction of urban underground logistics system. Urban Underground Logistics System (ULS) is a new concept of transportation and supply system for transporting solid goods within and between cities through underground pipes and tunnels, etc. The goods from the handled logistics bases or parks are distributed to each terminal through the underground logistics system. distribution to various terminals, which include supermarkets, factories, transit stations, and even neighborhoods [2].

Yicun Chen et al [3] analyzed the similarities and differences between underground logistics system (ULS) and subway, and conducted a feasibility analysis on the synergistic transportation of ULS and subway. Tao Yang [4] constructed a system dynamics model of the impact of underground logistics system on urban development. Yixin Zhao et al [5] used pneumatic bladder pipes for cargo transportation as a way to build an underground logistics system, and analyzed its feasibility in terms of technology, economic benefits, social benefits, and institutional guarantees. Yun Hua et al [6] analyzed the influencing factors of node location of underground logistics system based on the explanatory structure model with the objectives of economy, efficiency, convenience and synergy of

underground logistics system network. Wentao Yan et al [7] established a two-layer planning model considering both suppliers and customers to solve the underground logistics node siting problem. Liu Guiru et al [8] established a mathematical model of two-level underground logistics nodes, and used K-means algorithm and immune algorithm to solve the optimal siting plan of the first and second-level nodes.

The above research results mainly focus on the feasibility analysis, influence factor analysis and node siting of underground logistics system, but few articles consider the influence of node transit rate on the siting of underground logistics nodes. In this paper, a two-layer planning model is established and combined with genetic algorithm to determine the number and location of underground logistics nodes.

2. Problem Description

The most important component of the underground logistics system is the underground logistics nodes and transport channels, and the nodes at all levels are the key to the whole underground logistics network, whose location and number determine the layout and scale of the whole network and directly affect the construction cost and function, so this paper focuses on the study of the location of underground logistics nodes. First of all, this paper proposes to establish an underground logistics network, which consists of underground logistics nodes and transport channels between the nodes, in which the underground logistics nodes are divided into primary and secondary nodes, each node is connected with the ground and realize multimodal transportation, and the existence of logistics parks is only directly connected with the nearest primary nodes, and can transfer goods across regions. Each primary node is connected to each other and connected to several secondary nodes, and each secondary node is not connected to each other and indirectly connected to the logistics park through the primary node in the region. Therefore, the logistics park sends the goods to its nearest first-level node, and then the first-level node transports them to its subordinate second-level nodes, or transfers them to other first-level nodes. The schematic diagram of the connection between the logistics park and the logistics nodes is shown in Fig. 1.
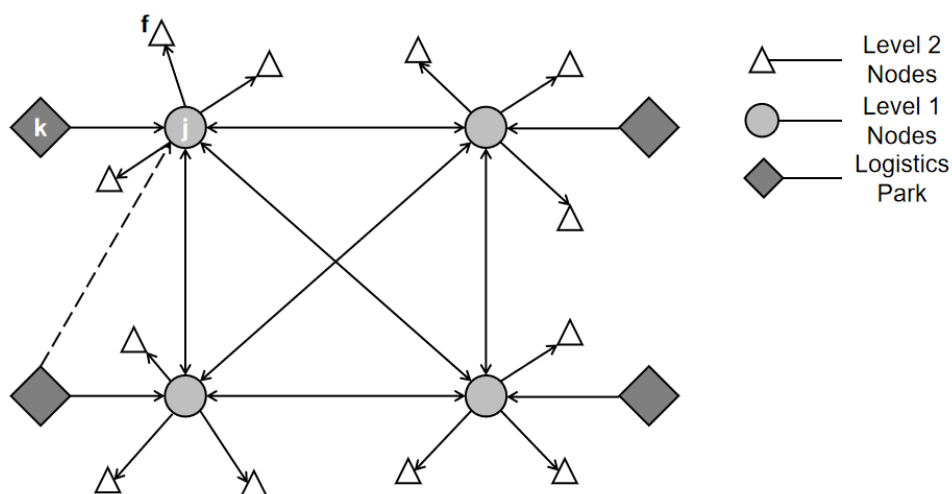

Fig. 1 Schematic diagram of the connection between logistics parks and logistics nodes

Based on this underground logistics system network, the underground logistics node location model is established, and the problem is solved optimally by using genetic algorithm, and the number and location of the underground logistics nodes are finally obtained by combining the traffic and freight area division map of a region and the corresponding freight flow matrix, the center point of each region and the area of the region, in order to provide a theoretical basis for the construction of

underground logistics network, realize multimodal transportation in urban areas, and do our best to relieve traffic congestion and improve logistics efficiency.

3. Establishing a Two-level Planning Model for Underground Logistics Node Site Selection

3.1 Model Assumptions

In order to simplify the problem to facilitate calculation and research, the thesis model is based on the following assumptions.

(1) It is assumed that all goods entering and leaving the logistics park are transported underground to each level node through underground transport channels.

(2) If a logistics node exists in a region, it is assumed that the logistics node will be established at the center of the region. And consider the center point of the freight region as the demand point, and assume that when the service scope of the logistics node covers the demand point, it is considered that the logistics node can provide service for the demand point.

(3) Assume that the transit between each node of the underground logistics system is transported through underground passages.

(4) The traffic impact of the transportation mode used when distributing goods from secondary nodes to the surface is not considered.

3.2 Explanation of Related Concepts and Symbols

3.2.1 Related Concept Notes

Primary node non-transfer volume: the cargo volume sent by the park to the nearest primary node through the underground logistics system or to the secondary node attached to it through that primary node.

Primary node transshipment volume: the amount of freight sent by the park through the underground logistics system to other primary nodes and their affiliated secondary nodes via the nearest primary node.

Large area: The total scope served by a primary node and its subordinate secondary nodes is a large area, and the large area does not include the park, which corresponds to the park one by one.

First-level node transfer rate (f_j): the percentage of cargo volume transferred from the logistics park to all other first-level nodes via the nearest first-level node to the total shipment volume of that logistics park is called the transfer rate of that first-level node. Due to the need to replace transportation vehicles, a low transshipment rate can reduce the workload under the premise of meeting transportation requirements.

3.2.2 Symbol Description

N : Denotes the set of logistics demand points, $N = \{1,2,...,i,...,n\}$, $i \leq n$.

M : denotes the set of logistics alternative nodes, $M = \{1,2,...,j,...,m\}$, $j \leq m$.

Q : Indicates a collection of logistics parks, $Q = \{1,2,...,k,...,q\}$, $k \leq q$.

S_{up} : denotes the upper-level planning objective function.

S_{down} : denotes the lower-level planning objective function.

$X_j \in \{0,1\}$: A decision variable indicating whether to establish a first-level logistics node at alternative node j. If a first-level node is established at j, X_j takes the value of 1; if a first-level node is not established at j, then X_j takes the value of 0.

$Y_j \in \{0,1\}$: A decision variable indicating whether to establish a secondary logistics node at alternative node j. If a secondary node is established at location j, Y_j takes the value of 1; if a secondary node is not established at j, then Y_j takes the value of 0.

$s_{ij} \in \{0,1\}$: 0-1 variable, if $s_{ij} = 1$, it means that demand point i is served by alternative node j; if $s_{ij} = 0$, it means that demand point i is not served by alternative node j.

d_{ij}: Denotes the distance from alternative node j to demand point i.

R: Denotes the maximum service radius of the alternative node, as a parameter.

w_i: Denotes the freight demand at demand point i.

D_j: Denotes the upper limit of the maximum service capacity of the alternative node j.

T_k: Denotes the shipment volume of logistics park k.

H_{kf}: Denotes the amount of freight sent from the primary node j, which is directly connected to the logistics park k, to the secondary node $f \in M$ under it.

O_{jf}: 0-1 variable, if $O_{jf} = 1$, it means that the primary node $j \in M$ is directly connected to the secondary node $f \in M$. If $O_{jf} = 0$, it means that the primary node $j \in M$ is not directly connected to the secondary node $f \in M$.

f_j: Denotes the transshipment rate of logistics node V.

T_k: Denotes the volume of shipments (transport demand) from logistics park $k \in Q$.

$z_{kj} \in \{0,1\}$: 0-1 variable, which indicates whether the goods of logistics park $k \in Q$ are output through the first-level node $j \in M$. If $z_{kj} = 1$, it means the goods of logistics park $k \in Q$ are output through the first-level node J. If $z_{kj} = 0$, it means the goods of logistics park K are output through the first-level node $j \in M$.

3.3 Model Building

3.3.1 Upper Level Planning

(1) Objective function

Since the smaller the number of logistics nodes, the lower the cost spent, the objective function of the upper level planning is the minimum number of underground logistics nodes, i.e.

$$\min S_{up} = \sum_{j \in M}(X_j + Y_j) \tag{1}$$

(2) Constraints

1) For each alternative node j, it can be at most a first-level node or a second-level node, but not both a first-level node and a second-level node.

$$X_j + Y_j \leq 1, \quad \forall j \in M \tag{2}$$

2) For each logistics demand point i, only one logistics node will serve it.

$$\sum_{j} s_{ij} = 1, \forall i \in N \tag{3}$$

3) Logical relationship constraint.

$$Y_j \geq s_{ij}, \forall i \in N, j \in M \tag{4}$$

4) The limitation of distance between logistics nodes and demand points.

Let the location of each alternative node be (O_{jx}, O_{jy}), the location of each logistics demand point be (E_{ix}, E_{iy}), and the distance from the alternative node j to the demand point i be d_{ij}, then $d_{ij} = \sqrt{(O_{jx} - E_{ix})^2 + (O_{jy} - E_{iy})^2}$.

$$d_{ij} s_{ji} \leq R, \quad \forall i \in N, j \in M \tag{5}$$

5) Logistics node service capacity limitation.

$$\sum_{i} w_i s_{ij} \leq D_j (X_j + Y_j), \forall j \in M \tag{6}$$

6) 0-1 constraint.

$$X_j \in \{0,1\} \tag{7}$$

$$Y_j \in \{0,1\} \tag{8}$$

3.3.2 Lower Level Planning

(1) Objective function

Since goods need to change transportation vehicles during transshipment, a low transshipment rate can reduce the workload under the premise of meeting transportation demand. Therefore, the objective function of the lower level planning is the lowest transshipment rate for the underground logistics primary node, i.e.

$$\min S_{\text{down}} = \sum_{j \in M} f_j \tag{9}$$

(2) Constraints

Since a logistics park is directly connected to only one primary node, and a primary node can be directly connected to multiple logistics parks, let the freight volume of primary node j directly connected to logistics park k to its subordinate secondary node $f \in M$ be H_{jf}; let O_{jf} be 0-1 variable, if $O_{jf} = 1$, it means that primary node $j \in M$ is directly connected to secondary node $f \in M$; if $O_{jf} = 0$, it means that primary node $j \in M$ is not directly connected to secondary node $f \in M$.

Therefore, the transit rate f_j of the primary node is formulated as follows:

$$f_j = \begin{cases} \dfrac{1}{T_k}(T_k - \sum_{f \in M} H_{jf} O_{jf}) \times 100\%, & \text{when } X_j = 1 \\ 0, & \text{when } X_j = 0 \end{cases} \tag{10}$$

1) Nodal transit rate constraint.

$$f_j \geq 1 - \frac{\sum_{i \in N} w_i s_{ij}}{T_k} - (1 - z_{kj}) \tag{11}$$

2) For each logistics park, there is one and only one primary node directly connected to it.

$$\sum_{j \in M} z_{kj} = 1, \forall k \in Q \tag{12}$$

$$X_j \geq z_{kj}, \forall k \in Q, j \in M \tag{13}$$

3) 0-1 constraint.

$$O_{kf} \in \{0,1\} \tag{14}$$

$$z_{kj} \in \{0,1\} \tag{15}$$

4. Genetic Algorithm based Solution Model

In this paper, we adopt genetic algorithm and use Matlab software to solve the urban underground logistics node siting model with the following procedure.

(1) Coding and decoding method

In order to solve the current decision problem efficiently, this paper integrates roulette mapping rules in the codec design of the current decision algorithm and has the basic parameters as follows: assuming that the total number of logistics alternative nodes is m, the total number of demand points is n, the total number of primary underground logistics nodes to be sited takes the value range of $\left[s_{min}^1, s_{max}^1\right]$, the total number of secondary underground logistics nodes to be sited takes the value range of $\left[s_{min}^2, s_{max}^2\right]$, then a three-level real number coding is used to represent the solution of the sited problem, and the value range of each dimensional coding is $[0,1]$.

1) Level 1

Code: $1 + s_{max}^1$ length, used to determine the number of underground logistics nodes and siting points at the first level.

Decoding: The first bit of the code is used to determine the number of first-level nodes to be addressed, assuming that s^1 first-level nodes need to be addressed, based on which s^1 first-level nodes can be selected from the current n demand nodes using the roulette rule.

2) Level 2

Code: $1 + s_{max}^2$ length, used to determine the number of secondary underground logistics nodes and site selection points.

Decoding: The first bit of the code is used to determine the number of secondary nodes to be addressed, assuming that s^2 secondary nodes need to be addressed, based on which s^2 secondary nodes can be selected from the current $(n - s^1)$ demand nodes using the roulette rule.

3) Level 3

Code: m length, used to determine the pairing of logistics zones with first-level nodes.

Decoding: According to the site selection result of layer 1 code, the roulette rule is used to determine the first-level node corresponding to each s^1 logistics park. Assuming that the site selection result of layer 1 code is s^1 first-level nodes, the probability values of this first-level node being selected are $1/s^1$.

Meanwhile, the matching relationship between demand nodes and secondary nodes, and secondary nodes and primary nodes are matched according to the nearest greedy rule.

(2) Adaptability function selection

Since this paper establishes a two-level planning node siting model, a linear weighting approach is used to simplify the objective function and take the inverse as the fitness function, i.e.

$$F(x) = \frac{1}{F_1 + \delta F_2} \tag{16}$$

Where is the F_1 upper-level planning objective function, is the F_2 lower-level planning objective function, and δ is the weight coefficient, which takes the value of 20.

(3) Selection operation

In this paper, we use the roulette wheel selection method, under which the probability of each individual being inherited into the next generation population is:

$$p(x_i) = \frac{f(x_i)}{\sum\limits_{j=1}^{N} f(x_j)} \tag{17}$$

(4) Crossover operation

Since this paper uses real numbers to encode individuals, the crossover operator uses the real number crossover method, which is as follows.

$$\begin{cases} a_{kj} = a_{kj}(1-b) + a_{lj}b \\ a_{lj} = a_{lj}(1-b) + a_{kj}b \end{cases} \tag{18}$$

Where b is a random number in the interval $[0,1]$ [9].

(5) Mutation operation

The j gene variant a_{ij} in the i individual is given by:

$$a_{ij} = \begin{cases} a_{ij} + (a_{ij} - a_{max}) * f(g), r \geq 0.5 \\ a_{ij} + (a_{min} - a_{ij}) * f(g), r < 0.5 \end{cases} \qquad (19)$$

Where a_{max} and a_{min} are the upper and lower bounds of gene a_{ij}, respectively; $f(g) = r(1 - g/G_{max})^2$, r are random numbers, $r \in [0,1]$, g and G_{max} are the current iteration number and the maximum evolution number, respectively [9].

5. Solution Analysis

Table 1. Selected Regional Data

Number	Demand Point Number	Center Point X (m)	Center Point Y (m)	Logistics park to freight regional freight volume (tons)			
				1	2	3	4
1	791	146277.00	149377.05	487.80	737.07	203.36	166.94
2	792	148037.42	149443.90	101.41	385.15	73.94	37.95
3	793	141732.23	149908.02	311.02	85.82	126.22	92.09
4	794	146343.98	150237.09	37.39	417.26	98.34	58.80
5	795	143903.27	150127.84	524.95	27.51	30.67	16.56
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
106	896	169251.06	165333.16	62.86	21.74	11.55	6.20
107	897	165295.96	166307.48	147.49	149.42	336.56	66.56
108	898	157354.70	166956.66	361.54	127.28	637.85	508.22
109	899	163428.02	166293.35	116.28	144.91	573.44	347.64
110	900	161442.73	165833.17	250.70	254.94	208.08	113.60

Based on the above genetic algorithm, the following example is solved by Matlab programming. There are 4 logistics parks and 110 traffic and freight areas (i.e. logistics demand areas) in a region, in which underground logistics alternative nodes are also generated. The coordinates of the center points of some regions (in meters) and the freight volume (in tons) from each logistics park to each region respectively are shown in the Table 1.

The initial population number is set to 20, the maximum number of iterations of the genetic algorithm is 300, the crossover probability is 0.7, and the variation probability is 0.3. The maximum handling capacity of the primary underground logistics node is 35,000 tons and the maximum coverage area is 30 km; the maximum handling capacity of the secondary underground logistics node is 6,000 tons and the maximum coverage area is 4 km.

Firstly, a schematic diagram of the location of the logistics park and each regional center point in the area is obtained as shown in the Fig. 2.
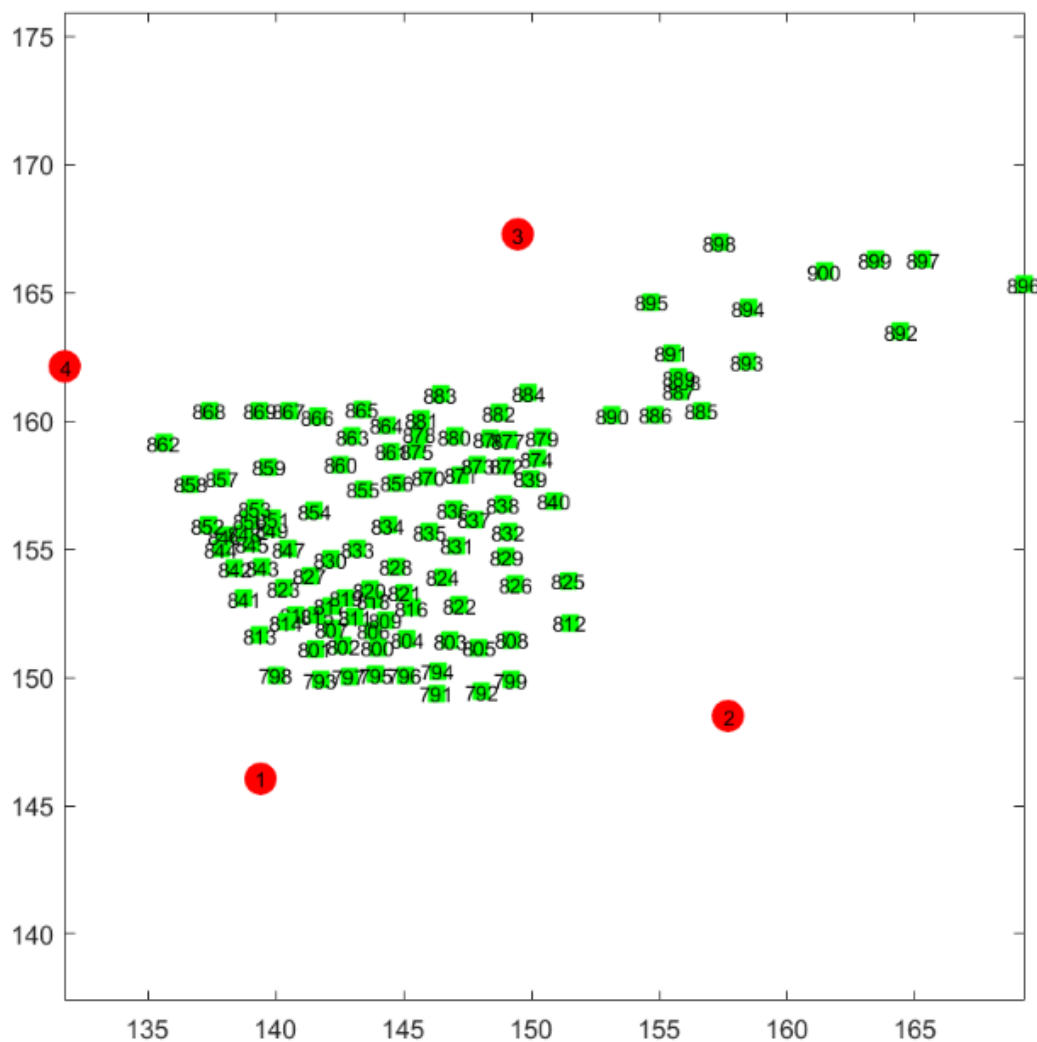
Fig. 2 Location schematic

For the 110 regions in the calculation example, the connection relationship between primary nodes and secondary nodes, secondary nodes and demand points is matched according to the greedy rule of closest distance. Through Matlab solution, 3 primary nodes and 16 secondary nodes that meet the optimization objectives are obtained. Table 2 shows the site selection results and the correspondence between the logistics park, primary nodes, secondary nodes and demand points. Table 2 shows that logistics park 1 and 4 are directly connected to the primary node 851, and 851 has 6 subordinate secondary nodes; logistics park 2 is connected to the primary node 823, and 823 has 5 subordinate secondary nodes; logistics park 3 is connected to the primary node 887, and 887 also has 5 subordinate secondary nodes.

Meanwhile, Fig. 3 shows the location results of logistics park, primary node, secondary node and demand point, as well as the connection channel between each point. From Fig. 3, we can know that the secondary nodes are always closely around the primary nodes they belong to, and the logistics demand points are always concentrated near the secondary nodes.

The corresponding cargo flow and transshipment volume of each first-level node are shown in Table 3, and the cargo transported through the first-level node to other first-level nodes is the transshipment volume of the node, so that the transshipment rate of each first-level node is calculated and the average transshipment rate is 48.84%, and the underground logistics network established in this paper effectively controls the transshipment rate of the node.

Table 2. Node Correspondence Table

| Logistics Park	Level 1 Node	Affiliated secondary nodes	Corresponding demand points
1	851	847	810, 813, 814, 817, 827, 830, 841, 843, 845, 847, 849, 854
		852	842, 844, 846, 848, 850, 852, 858
		859	853, 857, 859, 860
4		862	862
		869	866, 867, 868, 869
		881	855, 856, 861, 863, 864, 865, 870, 875, 878, 881, 883
2	823	797	793, 795, 796, 797, 798, 800, 801, 802, 807, 815
		803	791, 792, 794, 799, 803, 804, 805, 822
		821	806, 809, 811, 816, 818, 819, 820, 821, 824, 828, 833, 834, 835
		826	808, 812, 825, 826
		829	829, 831, 832, 836, 837, 838
3	887	874	839, 840, 874, 879
		876	871, 872, 873, 876, 877, 880, 882, 884
		891	885, 886, 888, 889, 890, 891, 895
		894	893;894;898;900
		897	892, 896, 897, 899
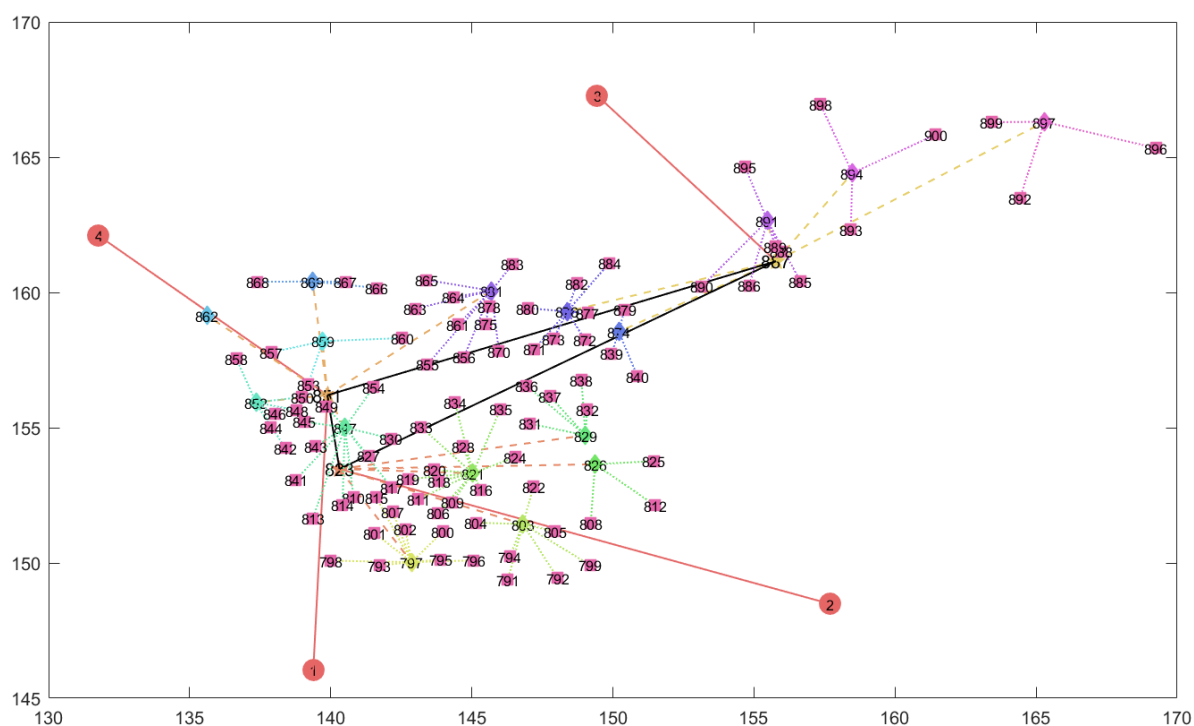
Fig. 3 Line Diagram

Table 3. Primary node transshipment rate

Level 1 Node	Cargo volume (tons)	Transshipment volume (tons)	Transit rate (%)	Average transit rate (%)
823	18168.52	8439.15	46.45	
851	26895.16	17193.28	63.93	48.84
887	17912.88	6474.28	36.14	

6. Conclusion

This paper combines the research results of domestic and foreign scholars on underground logistics system to construct underground logistics network. A two-layer planning model for urban underground logistics node siting is established, the underground logistics nodes are divided into two levels, the number of underground logistics nodes and the transit rate of the first-level nodes are used as the optimization objectives for node siting, and the relevant cases are solved by genetic algorithm. The validity and feasibility of the model are confirmed, and it contributes to the future research of node siting of underground logistics system.

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