Construction of a Class of Urban Underground Logistics Network

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Abstract

As the fifth type of underground transportation system of transportation and supply system, it can alleviate the increasingly serious urban traffic congestion problem. As the terminal of the system, the logistics node is mainly responsible for the management and control functions of the system and the storage and distribution of goods. An important part of the underground logistics system. This paper establishes the underground logistics node selection clustering model, the underground logistics node selection verification model, the underground network design double-layer optimization model, the underground logistics network improvement model, the underground logistics network timing and optimization model, and the traffic congestion through qualitative and quantitative methods. In-depth research and discussion on index, first-level node transit rate, node service coverage, freight volume index, construction and operation cost, underground network utilization, underground logistics network satisfaction, and urban transportation demand index.

Keywords

Underground logistics network, node selection, network satisfaction, traffic congestion index, dynamic programming.

1. Introduction

In recent years, the more and more serious traffic congestion problem in big cities has gradually become a difficult problem that needs to be solved urgently in the world's big cities. In order to effectively solve the increasingly serious traffic congestion problem in large cities, Japan, the Netherlands, the United States and other countries have turned their eyes to the underground, hoping to reduce the pressure of urban surface traffic and avoid environmental pollution by establishing an underground logistics system that can transfer the transportation, storage, sorting and other processes of most goods on the ground to the underground [1, 2]. Therefore, “overall planning for the development of underground and above-ground space" is imperative, and “underground logistics system" is receiving more and more attention from developed countries.

The underground logistics system (ULS) refers to the transportation and supply system of goods in and between cities through underground pipelines or tunnels similar to subways [3, 4]. It does not occupy the ground road, reducing the traffic pressure on the ground road, thus easing the traffic congestion in the city; it uses clean power to effectively reduce urban pollution. It is not interfered by external conditions, and transportation is more reliable and efficient. At the same time, the reduction of ground trucks brings huge external benefits, such as the cost of repairing damaged roads and the cost of environmental treatment, which can be used to compensate for the high investment in the construction of underground logistics systems.

The model established in this paper will break the traditional thinking of building the above-ground logistics network of hierarchical distribution, and establish the underground logistics node selection clustering model, the underground logistics node selection verification model, the underground network design double-layer optimization model, the underground logistics network improvement model, the underground logistics network timing and optimization model. The logistics freight volume is introduced into the model and used as the data basis of the model to build the urban underground logistics network model.

2. Model establishment

2.1 Selective clustering model for underground logistics nodes [5]

The choice of underground logistics nodes is mainly measured by the traffic congestion index of each region, the transshipment rate of the first-level nodes, the coverage of the nodes at all levels, and the strength of each node.

1) Regional traffic congestion index

According to the topic information, the traffic congestion index ranges from 0 to 10, and every 2 numbers are one grade, corresponding to “0-2 unblocked", “2-4 basically unblocked", " 4-6 mild congestion", " 6-8 moderate congestion" and " 8-10 severe congestion". The higher the value, the more serious the traffic congestion.

Due to the non-population-intensive area in the area, it can be approximated that the regional traffic congestion index is directly proportional to the total freight volume of the region reflected by the OD data. The fitting function of the traffic congestion index k and the total freight volume Q is as follows:

$$k_i(t) = 0.00267 \quad Q_i(t)$$

Where $k_i(t)$ the traffic congestion is index on the t day of the i regional node; $Q_i(t)$ is the total freight volume on the t day of the i node.

2) Primary node transfer rate

The amount of cargo transferred from the logistics park to the other all primary nodes via the nearest primary node accounts for the percentage of the total shipments of the logistics park, which is called the transshipment rate φ of the primary node. Due to the need to replace the transport vehicle, the low transfer rate can reduce the workload while meeting the transport requirements.

$$\varphi = \frac{\sum_{\min dyi=1}^{4} Q_{\min dyi}}{\sum_{qi=1}^{4} Q_{qi}}$$

Where $Q_{\min dyi}$ is the freight volume of the nearest primary node $\min dyi$ to all other nodes; Q_{qi} is the freight volume of the qi industrial park.

3) Coverage of node services at all levels

The coverage γ of the node service is the percentage of the area covered by the node service as a percentage of the total area of the area.

$$\gamma_i = \frac{\sum_{i=1}^{n} S_i}{S}$$

Where S is the total area of the area, and S_i is the service coverage area of the i node.

4) Strength of each node

Consider the weight of the weighted network sideband, and define the intensity q_i of the point as:

$$q_i = \sum_{i \in N_i} w_{ij}$$

Where w_{ij} is the weight of point i and point j

The weight between the two points is determined by the amount of freight and the distance between them. $w_{ij} = \mu_1 q(i, j) + \mu_2 S(i, j)$

Where $q(i, j)$ represents the amount of freight between point i and point j, and $S(i, j)$ represents the distance between point i and point j. Considering the construction cost of the underground logistics system and the corresponding total cargo transportation volume, the weight $\mu_1 = \mu_2 = 0.5$ can be taken, that is, the planning of the underground logistics system has no preference for the distance and the total freight volume.

2.1.1 Selection clustering objective function of underground logistics node

The goal of node selection is to minimize the transport rate of the primary node, the maximum coverage of the node service, and the greatest improvement of the traffic congestion index.

1) Primary node has the lowest transport rate

Primary node transfer rate is $\varphi = \frac{\sum_{\min dyi=1}^{4} Q_{\min dyi}}{\sum_{qi=1}^{4} Q_{qi}}$, Where $Q_{\min dyi}$ is the freight volume of the nearest primary node $\min dyi$ to all other nodes; Q_{qi} is the freight volume of the qi industrial park.

2) Node service coverage is as large as possible

Coverage γ of node services is the percentage of the area covered by node services to the total area of the area. $\gamma_i = \frac{\sum_{i=1}^{n} S_i}{S}$, where S is the total area of the area and S_i is the coverage area of the i node.

3) The greatest improvement in the traffic congestion index

$$\Delta k = \sum_{i=1}^{n} \left[k_i(0) - k_i(t) \right]$$

Among them, the traffic congestion index on the day of $k_i(0)$, $k_i(t)$ indicates the traffic congestion index of the i th node on the t th day.

In summary, the final objective function is as follows:

$$\max W = \max(-\varphi) + \max\gamma + \max\Delta k$$

$$= \frac{\sum_{i=1}^{n} S_i}{S} + \sum_{i=1}^{n} \left[k_i(0) - k_i(t) \right] - \frac{\sum_{\min dyi=1}^{4} Q_{\min dyi}}{\sum_{qi=1}^{4} Q_{qi}}$$

2.1.2 Constraints for the selection of underground logistics nodes

From the analysis, it can be seen that the relevant constraints when selecting underground logistics nodes are: the upper limit of freight volume of primary and secondary nodes, the distance between underground nodes that are open to traffic is restricted by the flight and vehicle speed, and goods entering and leaving the four logistics parks are transported underground as much as possible.

1) Upper limit constraint of cargo quantity of primary node

The upper limit of the ground level of the first-level node is 4,000 tons, then there are: $Q' \le 4000$

2) Upper limit constraint of cargo quantity of secondary nodes

The upper limit of the ground level of the second-level node is 3,000 tons, then there are: $Q'' \le 3000$

3) The distance between the underground nodes of traffic is restricted by the speed of flights and vehicles. $d(i,j) \le 9800$

4) Goods entering and leaving the 4 logistics parks should be placed in underground transportation as much as possible.

$$Q_\lambda \le \frac{\sum_{qi=1}^{4} Q_{qi}}{Q'_{\max}}$$

2.1.3 Determine the final model

According to the model established above, the final model is:

$$\max W = \max(-\varphi) + \max\gamma + \max\Delta k$$

$$= \frac{\sum_{i=1}^{n} S_i}{S} + \sum_{i=1}^{n}\left[k_i(0) - k_i(t)\right] - \frac{\sum_{\min dyi=1}^{4} Q_{\min dyi}}{\sum_{qi=1}^{4} Q_{qi}}$$

$$s.t.\begin{cases} Q' \le 4000 \\ Q'' \le 3000 \\ d(i,j) \le 9800 \\ Q_\lambda \le \dfrac{\sum_{qi=1}^{4} Q_{qi}}{Q'_{\max}} \end{cases}$$

2.2 Double-layer optimization model of underground logistics network [6,7]

Bi-level planning is widely used in transportation factors, economic dispatching, distribution system optimization planning, etc. The mathematical double-layer optimization model can be described as:

$$\min J_1 = F(x, y_1, y_2, y_3, \cdots, y_m) \quad s.t. G(x) \le 0$$

$$\min J_2 = f(x, y_1, y_2, y_3, \cdots, y_m) \quad s.t. g(x, y_1, y_2, y_3, \cdots, y_m) \le 0$$

In this paper, a bi-level optimization planning method is used to optimize the selection of underground logistics network. The upper layer is a congestion improvement module, which is used to find the optimal degree of congestion improvement, including traffic congestion index, above-ground cargo transportation volume and underground cargo transportation volume. The lower layer is the logistics cost optimization module, which is used to calculate the optimization of logistics cost, including the length of underground logistics lines and the amount of goods transported by vehicles on the ground. Bi-level optimization consists of two levels. The upper level decision results will generally affect the lower level goals and constraints, while the lower level will feedback the decision results to the upper level, thus realizing the upper level. The interaction of lower-level decisions is shown in the two-level optimization logic diagram 1.

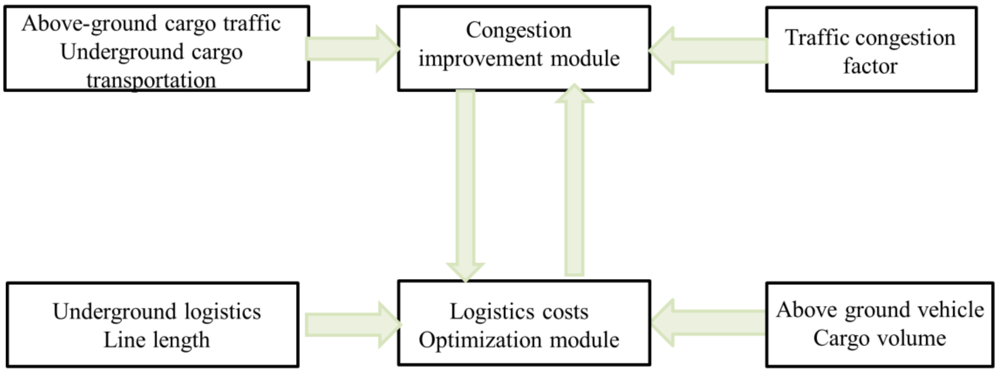

Figure 1: Double layer optimization logic diagram

2.2.1 Upper congestion improvement model

1) Index definition

a) Underground level node freight volume index A_{yi}

Definition: The underground first-level node freight volume index A_{yi} is expressed as the maximum percentage of underground freight in the first-level node yi and the first-level node:

$$A_{yi} = \frac{Q_{yi}}{Q_{yi\max}}$$

b) Underground second node freight volume index A_{ti}

Definition: The underground secondary node freight volume index A_{ti} is expressed as the percentage of the maximum underground cargo volume in the secondary node ti and the secondary node:

$$A_{ti} = \frac{Q_{ti}}{Q_{ti\max}}$$

2) Selection of objective function

The congestion improvement performance in the underground logistics system is selected as the evaluation index: $\max F = \max(F_1 + F_2)$

a) Traffic congestion index improvement:

$$F_1 = \Delta k = \sum_{i=1}^{n}\left[k_i(0) - k_i(t)\right]$$

Among them, $k_i(0)$ is the traffic congestion index on the day of the initial day, and $k_i(t)$ represents the traffic congestion index of the i th node on the t th day.

b) Degree of cargo dispersion

Due to the high cost and operating cost of the underground logistics system, the freight capacity of the underground nodes should be fully utilized, that is, the freight volume index of each node should be as large as possible: $F_2 = \sum_{yi=1}^{yn} A_{yi} + \sum_{ti=1}^{tn} A_{ti}$

Then the objective function is

$$\begin{aligned}\max F &= \max(F_1 + F_2)\\ &= \sum_{i=1}^{n}\left[k_i(0) - k_i(t)\right] + \sum_{yi=1}^{yn} A_{yi} + \sum_{ti=1}^{tn} A_{ti}\end{aligned}$$

3) Model constraints

a) Due to the basic requirements for improved traffic conditions in various regions, the traffic is smooth, at least basically smooth, then: $0 \le k(t) \le 4$

b) Because the underground nodes and the goods in the channel are required to be cleared every day, the daily purchase amount $M_i(t)$ of the lower nodes is equal to the daily shipment $N_i(t)$, namely: $M_i(t) = N_i(t)$

Where $M_i(t)$ represents the amount of purchase of the underground node i on the t th day, $N_i(t)$ represents the shipment of the underground node i on the t th day, and the total freight volume is equal to the purchase quantity plus the shipment volume:

$$Q_i(t) = M_i(t) + N_i(t)$$

4) Establish the final model

According to the above-mentioned upper congestion improvement model, the final model can be obtained as follows:

$$\begin{aligned} \max F &= \max(F_1 + F_2) \\ &= \sum_{i=1}^{n}\left[k_i(0) - k_i(t)\right] + \sum_{yi=1}^{yn} A_{yi} + \sum_{ti=1}^{tn} A_{ti} \end{aligned}$$

$$s.t.\begin{cases} 0 \le k(t) \le 4 \\ M_i(t) = N_i(t) \\ Q_i(t) = M_i(t) + N_i(t) \end{cases}$$

2.2.2 Lower logistics cost improvement model

1) Selection of objective function

Since one of the objectives of selecting an underground logistics network is to reduce the logistics cost, the cost optimization model in the underground logistics system is selected as the evaluation index: $\min F = \min(F_3 + F_4 + F_5)$

a) Annual average inter-node line cost depreciation:

Assuming that the design period of the underground logistics system channel is 100 years and the annual comprehensive depreciation rate is 1%, there are:

$$F_3 = [\sum_{i=1, j=1}^{n} S_i(i, j) \times \lambda(i, j) + C_{yn} yn + C_{tn} tn] \times Z$$

Where $S_i(i, j)$ is the distance between node i and node j, and $\lambda(i, j)$ is the construction unit cost of the underground logistics system, indicating the unit construction cost of node i to node j. C_{yn} represents the cost of the first node, C_{tn} represents the unit cost of the second node, and Z represents the project depreciation.

Now analyze $\lambda(i, j)$: if there are campus nodes in node i and node j, then

$$\lambda(i, j) = \begin{cases} 5 & \text{Two-way four-track (10}tons\text{)} \\ 4 & \text{Two-way dual track (10}tons\text{)} \\ 3.5 & \text{Two-way four-track (5}tons\text{)} \\ 3 & \text{Two-way dual track (5}tons\text{)} \end{cases}$$

If there is no campus in node i and node j, then:

$$\lambda(i, j) = \begin{cases} 3.5 & \text{Two-way four-track (5}tons\text{)} \\ 3 & \text{Two-way dual track (5}tons\text{)} \end{cases}$$

b) Freight transportation costs

Assuming that the average transportation cost per ton per kilometer is always equal, at 1 yuan / ton km, there are:

$$F_4 = \sum_{i=1, j=1}^{n} \frac{S_i(i,j) \times S_{dis}(i,j)}{2}$$

That is, the objective function is

$$\min F = \min(F_3 + F_4 + F_5)$$
$$= [\sum_{i=1, j=1}^{n} S_i(i,j) \times \lambda(i,j) + C_{yn} yn + C_{tn} tn] \times Z + \sum_{i=1, j=1}^{n} \frac{S_i(i,j) \times S_{dis}(i,j)}{2}$$

2) Establishment of constraints

a) First-level node cargo limit constraint

The upper limit of the ground level of the first-level node is 4,000 tons, then there are: $Q' \le 4000$

b) The upper limit of the cargo quantity of the secondary node

The upper limit of the ground level of the second-level node is 3,000 tons, then there are: $Q'' \le 3000$

c) The distance between the underground nodes of traffic is restricted by the speed of flights and vehicles. $d(i,j) \le 6000$

3) Final model

$$\min F = \min(F_3 + F_4 + F_5)$$
$$= [\sum_{i=1, j=1}^{n} S_i(i,j) \times \lambda(i,j) + C_{yn} yn + C_{tn} tn] \times Z + \sum_{i=1, j=1}^{n} \frac{S_i(i,j) \times S_{dis}(i,j)}{2}$$

$$s.t. \begin{cases} Q' \le 4000 \\ Q'' \le 3000 \\ d(i,j) \le 6000 \end{cases}$$

2.3 Improvement of the two-layer model [8]

The underground logistics network was established to solve the problem of traffic congestion on the ground. Therefore, the basis for the improvement of the underground logistics network is to solve the problem of traffic congestion on the ground under the premise of meeting economics. The improved model of underground logistics network is divided into three sub-models, namely, the underground logistics network satisfaction model, the underground logistics network anti-risk inspection model, and the underground logistics network adjustment model.

2.3.1 Underground Logistics Network Satisfaction Model

The underground logistics network satisfaction model is an evaluation model, which is intended to discriminate the role of the known underground logistics network model in solving the traffic congestion problem and the calculation of the overall utilization degree of the network. The underground logistics network satisfaction index m, which consists of two indicators: the underground network utilization rate G and the traffic congestion index improvement situation Δk, as follows:

$$m = q_1 G + q_2 \Delta k$$

Where A and B are the weights of the corresponding indicators

2.3.2 Anti-risk test model for underground logistics network

The underground logistics network model anti-risk test model is a test model, which is intended to judge the anti-risk ability of the underground logistics network model.

Maximum Channel Interrupt Number $n_{bd\max}$: The maximum number of interrupt lines allowed in the underground logistics network.

The primary node allows a net increase in volume ACC_{yi}: the maximum net increase in volume that the primary node can allow.

The first-level node allows a net increase in shipments ACO_{yi}: the maximum net increase in shipments that the first-level node can allow.

The secondary node allows a net increase in volume ACC_{ti}: the maximum net increase in volume that the secondary node can tolerate.

The secondary node allows a net increase in shipment ACO_{ti}: the maximum net increase in shipments that the secondary node can tolerate.

Definition: Underground Logistics Network Anti-risk Index n

$$n = q_1 n_{bd\max} + q_2 ACC_{yi} + q_3 ACO_{yi} + q_4 ACC_{ti} + q_5 ACO_{ti}$$

The larger the index, the stronger the system's ability to resist risks.

2.3.3 Underground logistics network adjustment model

The underground logistics network adjustment model is a network optimization model, which is intended to optimize the network's satisfaction and anti-risk capabilities. Based on the double-layer optimization, the underground logistics network adjustment model is established. The upper layer is the satisfaction optimization module, and the lower layer is the anti-risk capability optimization module.

1) Upper level satisfaction adjustment

The objective function is: $m = q_1 G + q_2 \Delta k$

Constraints for congestion improvement models:

a) The traffic congestion index of freight OD in the region will be improved to smooth traffic (0-2), at least basically smooth (2-4). $0 \le k(t) \le 4$

b) Because the underground nodes and the goods in the channel are required to be cleared every day, the daily purchase amount $M_i(t)$ of the lower nodes is equal to the daily shipment $N_i(t)$, namely: $M_i(t) = N_i(t)$

Where $M_i(t)$ represents the amount of purchase of the underground node i on the tth day, $N_i(t)$ represents the shipment of the underground node i on the tth day, and the total freight volume is equal to the purchase quantity plus the shipment volume: $Q_i(t) = M_i(t) + N_i(t)$

c) The upper limit of the ground level of the first-level node is 4,000 tons, then there are: $Q' \le 4000$

d) The upper limit of the ground level of the second-level node is 3,000 tons, and then there are: $Q'' \le 3000$

c) The distance between the underground nodes that are open to traffic is constrained by the speed of flights and vehicles. $d(i, j) \le 9800$

2) Optimization of the underlying risk resistance

Objective function: $n = -q_1 n_{bd\max} + q_2 ACC_{yi} + q_3 ACO_{yi} + q_4 ACC_{ti} + q_5 ACO_{ti}$

The constraints of the lower level of risk resistance optimization:

a) Maximum channel interrupt number constraint:

$$0 \le n_{bd\max} \le 2n$$

b) Level 1 node allows net increase in volume constraints：

$$0 \le ACC_{yi} + Q_{yi} \le 4000$$

c) Level 1 nodes allow net increase in shipment constraints:

$$0 \le ACO_{yi} + Q_{yi} \le 4000$$

d) Secondary nodes allow net increase in volume constraints:

$$0 \le ACC_{ti} + Q_{ti} \le 3000$$

e) Secondary nodes allow net increase in shipment constraints:

$$0 \le ACO_{ti} + Q_{ti} \le 3000$$

In summary, the final model is:

$$m = q_1 G + q_2 \Delta k$$

$$s.t.\begin{cases} 0 \le k(t) \le 4 \\ M_i(t) = N_i(t) \\ Q_i(t) = M_i(t) + N_i(t) \\ Q' \le 4000 \\ Q'' \le 3000 \\ d(i, j) \le 9800 \end{cases}$$

$$n = -q_1 n_{bd\max} + q_2 ACC_{yi} + q_3 ACO_{yi} + q_4 ACC_{ti} + q_5 ACO_{ti}$$

$$s.t.\begin{cases} 0 \le n_{bd\max} \le 2n \\ 0 \le ACC_{yi} + Q_{yi} \le 4000 \\ 0 \le ACO_{yi} + Q_{yi} \le 4000 \\ 0 \le ACC_{ti} + Q_{ti} \le 3000 \\ 0 \le ACO_{ti} + Q_{ti} \le 3000 \end{cases}$$

3. Example analysis

Taking the traffic and freight area division map of Nanjing Xianlin area and the corresponding freight flow matrix, the regional center point and area of each area, and the traffic congestion coefficient of each area as examples, the underground logistics network is constructed and the implementation effect is analyzed.

3.1 Selection of underground logistics nodes

The node selection model including constraints and targets is solved according to the *ISODATA* algorithm flow.

3.1.1 Selection of nodes at all levels

Through the clustering calculation of the nodes, 8 first-level nodes and 22 second-level nodes are obtained. The specific nodes are shown in Table 1.

Table 1: Node selection

Primary node	Corresponding secondary node
894	898
888	891, 886
803	792, 799, 796
817	814, 793, 827, 828
870	864, 855, 836, 876
832	826, 839
897	896, 899, 892
853	844, 857, 859

From the table1, we can see the corresponding situation between the nodes at different levels. It can be found that the secondary nodes between different regions can only transport goods through the underground logistics network through the nodes of the first-level node and other regions.

3.1.2 Service range and coverage of nodes at all levels

Since the service radius of all nodes is freely selected within 3 km, the service range can be solved by image overlay. The total area of the node area is, except for the overlap area, there is a node coverage rate.

3.1.3 Actual cargo volume at each level of nodes

Due to the existence of the first and second nodes, the freight volume of each node will also change. The freight volume of the first and second nodes is shown in the table. After the construction of the underground logistics system network, a considerable proportion of cargo transportation is carried out from the underground logistics system network, thereby reducing the impact of cargo transportation on ground transportation. (See Table 2 for the actual cargo volume of the first and second nodes)

Table 2: Specific freight volume of each node

Regional division	Primary node	Total freight volume (tons)	Secondary node	Total freight volume (tons)
Area 1	894	10962.12	898	9471.287
Area 2	888	9776.106	891	5491.618
Area 3	803	10496.836	886	5021.806
			796	4080.732
			799	4208.726
			792	4802.31
Area 4	817	12877.032	814	4072.908
			793	3712.142
			827	4713.744
			828	4032.212
Area 5	870	11286.338	864	4433.886
			855	4936.81
			836	3900.994
			876	4053.574
Area 6	832	13549.12	826	5586.664
			839	6059.842
Area 7	897	13707.436	892	5202.043
			899	7457.395
			897	5225.575
Area 8	853	12138.282	844	5090.308
			857	4813.096
			859	4415.266

3.1.4 Transfer rate of each level node

According to the definition of the transfer rate of the first-level node, it is only necessary to calculate the percentage of the total shipments of the logistics park from the nearest primary node of the logistics park to all other first-level nodes, and the relevant first-level node transporter. The rate is shown in Table 3.

Table 3: Transit rate of each level node

Primary node	Primary node transfer rate
817	34.12%
803	30.42%
888	29.14%
853	77.91%
894	25.31%
870	56.48%
832	32.94%
897	28.66%

3.2 Design of the underground passage network

In summary, the established two-layer optimal model is:

$$\max F = \max(F_1 + F_2)$$
$$= \sum_{i=1}^{n}\left[k_i(0) - k_i(t)\right] + \sum_{yi=1}^{yn} A_{yi} + \sum_{ti=1}^{tn} A_{ti}$$
$$s.t.\begin{cases} 0 \le k(t) \le 4 \\ M_i(t) = N_i(t) \\ Q_i(t) = M_i(t) + N_i(t) \end{cases}$$

$$\min F = \min(F_3 + F_4 + F_5)$$
$$= [\sum_{i=1, j=1}^{n} S_i(i, j) \times \lambda(i, j) + C_{yn} yn + C_{tn} tn] \times Z + \sum_{i=1, j=1}^{n} \frac{S_i(i, j) \times S_{dis}(i, j)}{2}$$
$$s.t.\begin{cases} Q' \le 4000 \\ Q'' \le 3000 \\ d(i, j) \le 6000 \end{cases}$$

Using the model established above, the solution was solved using MATLAB software. Based on the improved particle swarm optimization algorithm, the upper layer first gives the decision, and the lower layer is guided by the value of the control variable. The lower layer finds its best strategy given the decision of the upper layer and gives its best strategy. The variable is fed back to the upper layer; in order to maximize its own interests, the upper layer adjusts its own scheme according to the reaction of the lower layer, makes a decision again, and then iterates between the upper and lower layers, and simultaneously optimizes the upper and lower layers of the bilevel programming, and finally The approximate global optimal solution of the bilevel programming model is solved. In this paper, based on the idea of improved particle swarm optimization algorithm, the optimal network can be used to alleviate traffic congestion and reduce the cost of lower logistics. The underground route establishes the "underground logistics system" network in the area.

3.2.1 Network composition

The optimized network obtained by the two-layer optimization algorithm is shown in Fig. 2, where the thick red line indicates bidirectional four-track (double hole) (10 tons), the thin red line indicates bidirectional double-track (double hole) (10 tons), and the thick blue line indicates two-way. Four-track (double-hole) (5 tons) and thin blue lines indicate two-way dual-track (double-hole) (5 tons). As can be seen from Figure 2, the route from the campus to the nearest primary node is a two-way four-track (double-hole) (10-ton) line, indicating that the park is more dependent on these primary nodes. The lines between nodes 888 and 891 and 817 and 827 are two-way four-track (double-hole)

(5-ton) lines, indicating that the correlation between the first- and second-level nodes is strong in their respective regions, and the corresponding secondary nodes can be It is called a "quasi-level node."

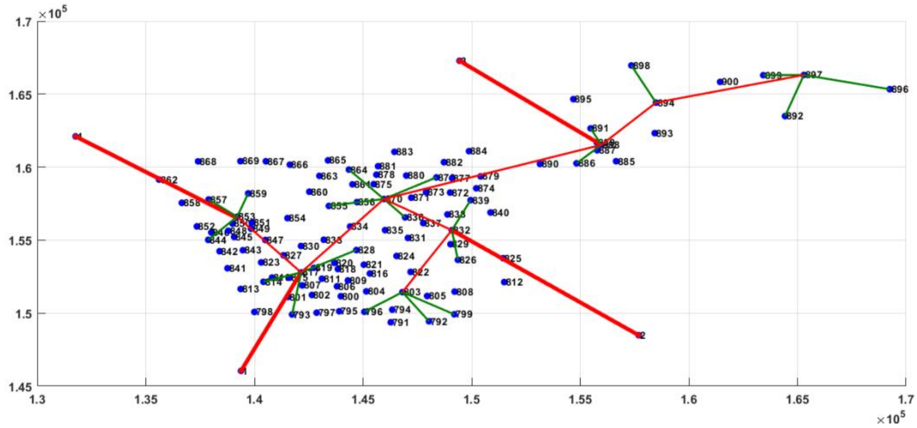

Figure 2: Underground Logistics Network Diagram

3.2.2 Actual freight volume of each node

Due to the construction of the underground logistics network, all levels of nodes can use the underground logistics network to carry out the transfer of goods. According to the results, the underground freight volume of most nodes is significantly higher than the ground freight volume.

Table 4: Actual freight volume of each node

Regional division	Primary node	Total freight volume (tons)	Secondary node	Total freight volume (tons)
Area1	894	12334.864	898	9471.224
Area 2	888	9375.702	891	5491.618
Area 3	803	16496.036	886	5021.806
			796	4080.732
			799	4208.726
			792	4802.31
Area 4	817	13304.392	814	4072.908
			793	3712.142
			827	4713.744
			828	4032.212
Area 5	870	12026.258	864	4433.886
			855	4936.81
			836	3900.994
			876	4053.574
Area 6	832	11717.952	826	5586.666
			839	6059.842
Area 7	897	14107.238	892	5201.524
			899	7457.388
			897	5225.566
Area 8	853	13977.862	844	5090.308
			857	4813.096
			859	4415.266

3.2.3 Actual flow rate of each channel

The flow rate of each channel actually reflects the degree of relief of traffic congestion in the underground logistics system network. It can be seen from Table 8 that the underground matter flow of most of the channels is higher than the ground flow, indicating that the underground logistics network plays a vital role in alleviating the traffic congestion.

Table 5: Actual flow rate of each channel

node	Connected line node	Total flow (tons)
894	898	4099.41
	888	1566.90
	897	1581.86
888	891	2893.60
	886	1787.68
	894	1740.90
	870	1638.35
803	796	2032.96
	799	2062.23
	792	1946.32
	832	1819.26
817	814	2196.60
	793	2051.73
	827	2409.37
	828	2198.27
	870	1854.35
	853	1531.25
870	864	2396.56
	855	2481.30
	836	2044.30
	876	2059.59
	888	1467.04
	817	1449.89
	832	1457.97
832	826	2255.50
	839	2881.50
	803	1687.23
	870	1563.36
897	892	2020.37
	899	2736.37
	896	2127.58
	894	1768.15
853	844	2564.87
	857	2450.93
	859	2146.28
	817	1448.42

3.2.4 Change in the transfer rate of the primary node

After the design of the underground logistics system network, the transshipment rate of the first-level nodes has been reduced to a certain extent, indicating that the first-level node transit rate decreases with the construction of the network model, and the scientific nature of the network construction is explained from another angle.

Table 6: Level 1 node transfer rate

Primary node	Primary node transfer rate	Rate of change
817	34.12%	-2.93%
803	27.68%	-9.01%
888	28.99%	-0.51%
853	56.98%	-26.86%
894	25.31%	-8.63%
870	56.48%	-0.86%
832	32.94%	-15.32%
897	28.66%	-6.85%

3.2.5 Depreciation and operating costs of underground logistics networks

The annual construction depreciation and operating costs obtained from the network optimization based on the two-tier optimization model are RMB 5,756,533,247.

4. Conclusion

In order to solve the problem of urban traffic congestion, the urban underground logistics system provides an effective and effective method, and the operational efficiency of the network will directly affect the operating costs and the economic and social benefits after completion. The mathematical model of a city underground logistics network is established by using ISODATA algorithm, particle swarm optimization algorithm, Dijkstra algorithm and simulated annealing algorithm. The accuracy and practicability of the model are verified by an example.

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