Modeling Node Layout Plans For Urban Underground Logistics Systems

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Abstract

The surge in urban traffic demand has led to a significant increase in the number of vehicles on the ground, resulting in urban traffic congestion; a large proportion of this traffic consists of commercial cargo. The resulting costs of traffic congestion are significant, with economic and environmental impacts. Investigating how to alleviate this congestion is an important and challenging research area. There are limitations on the ground transportation network, and the development of traditional urban logistics is nearing its limit. Therefore, new transportation methods are emerging as alternatives to address this problem including urban underground logistics. This study systematically examines the node positioning problem in planning urban underground logistics systems. These systems consist of interconnected logistics and distribution centers, which have distinct capabilities and constraints. The planning problem is investigated using the principle of distribution and its influencing factors, while considering the distinct functions of the centers. The results of this analysis are captured in two novel layout planning models: one for logistics centers and a second for distribution centers. For planning a logistics center, the requirement of each demand point is considered with a set covering model. This model is analyzed using the LINGO solution, with the goal of minimizing the construction costs. For planning a distribution center, the 0-1 mixed integer programming model is constructed, and an improved Bat-inspired Algorithm is adopted and solved in MATLAB. Finally, taking the layout planning of urban underground logistics system within the central ring road of Shanghai as an example, the layout model and rationality of the algorithm are validated. The novel models provide a theoretical foundation for the further study of urban underground logistics system.

***Keywords*:** urban underground logistics, logistics nodes, layout research, Bat-inspired Algorithm, improved algorithm

1. Introduction

With the on-going development of global economics and trade, the speed of goods circulating in various countries around the world continues to increase. As a result, traffic congestion has become one of the problems encountered by the world's major cities. Significant costs ensue from this congestion, including financial, environmental, wasted resources, in addition to impediments to economic development and growth. According to the data released by the Ministry of Transport in recent years, the direct or indirect economic losses caused by traffic congestion are equivalent to 5-8 percentage points of GDP. Residents of 15 large cities in China spend 2.88 billion minutes more on work each day than residents of developed countries in Europe[1]. At the same time, major cities have already experienced varying levels of traffic congestion. A large number of studies have shown that stop and go traffic leads to crude oil consumption accounting for 20% of the world's total consumption. According to the data released by the annual meeting of urban transportation planning, in terms of oil consumption, China's transportation oil consumption accounted for 54% of total consumption; the transportation energy consumption has accounted for more than 10% of the total social energy consumption, and consumption has increased year by year. Consequences include high levels of emissions and pollution[2].

The problem of traffic congestion in China and its relationship to the transportation of goods continues to gain recognition. There are ten cities in mainland China that have been ranked in the top 30 cities of the world with the highest levels of traffic congestion. The cities by ranking are: Chongqing, Tianjin, Beijing, Guangzhou, Chengdu, Shanghai, Shijiazhuang, Fuzhou, Shenyang and Hangzhou[3]. The most direct manifestation of traffic congestion is the excessive number of vehicles driving on the road. These are mainly composed of manned passenger vehicles and trucks. The trucks have a key role in the transportation of goods, as they move the majority of the total freight volume in many cities. The main reason for traffic congestion in cities is the huge increase in the number of vehicles on the ground roads caused by the surge in traffic demand; part of this surge comes from an increased demand for cargo logistics.

The numerous problems brought about by increased traffic congestion are significant. For example, environmental pollution is increasing, traffic accidents are frequent, valuable resources are wasted, and the ability to efficiently move goods is impeded, creating obstacles to further development. Therefore, all countries in the world are actively exploring ways to solve the urban traffic problems. In particular, the need to improve the efficiency of handling freight traffic is an important and challenging problem that is receiving much attention in the research community. Results have been reported on the theoretical and practical limitations of increasing the ground transportation facilities to meet the ever-increasing traffic demand. Given the limits of ground transportation systems, underground logistics systems are being explored. An urban underground logistics system can cooperate with other traditional modes of transportation to form an integrated transportation system to comprehensively solve the above-mentioned traffic problems. Therefore, coordinating the planning of ground and underground space development is imperative, and the potential benefits of deploying an underground logistics system (ULS) are receiving more and more attention in developed countries.

The development and utilization of underground space has become a global issue. A complete underground logistics network is composed of out-of-town logistics parks, logistics lines, logistics nodes (logistics centers and distribution centers), and dedicated vehicles. The logistics node is a key element of the underground logistics network. Its location determines the layout and scale of the entire logistics network, directly affecting the construction cost of the system and the service level to customers.

The main research contribution of this paper is to define new, layout planning models for urban underground logistics systems that produce a more reasonable and scientific layout pattern. First, we determine the quantity of logistics centers through the set covering model to meet the requirement of each demand point and determine the minimum construction cost. Second, we use the 0-1 planning model to plan the distribution service centers connected to each logistics center. An improved Bat algorithm, based on Levi's flight behavior, is introduced and programmed in MATLAB to solve the layout model of the urban underground distribution center.

This innovative research provides a reference scheme for actual site selection in the future. The underground logistics models introduced a low-carbon, energy-saving, and sustainable system. Its successful application can help to fundamentally alleviate traffic congestion problems, improve the speed and efficiency of logistics systems, effectively reduce pollution and save resources, and optimize logistics networks. This work is grounded on an analysis of the ULS issues in China; consequently, the results provide effective solutions to solve the traffic problems in China's big cities and improve logistics efficiency.

The remainder of this paper is structured as follows. Related work is presented in Section 2. The foundations of the ULS logistics node layout are presented in Section 3. Section 4 presents the new ULS planning layout models (logistics and distribution centers) and the improved Bat-inspired Algorithm. A case study example on panning a ULS for the central ring road of Shanghai is presented in Section 5. Section 6 presents a summary of the results.

2. Related work

The modern urban ULS is considered to be an important means of solving urban traffic problems. Since the 1990s, the ULS has attracted the attention of researchers and practitioners from the United States (Rezaie et al., 2016) [4], Germany (Stein, 2003) [5], the Netherlands (Visser, 2010) [6], and Japan (Taniguchi, 2002) [7]). Much of the research has focused on related concepts and technologies, feasibility, and layout planning. Brief summaries of the work in these areas are presented below.

2.1. Related concepts and technologies

For the research on the conceptual parameters of underground logistics and related transportation technologies, foreign scholars mainly focus on the vehicles and technical parameters. Hyeok-bin Kwon and Seung-yup Jang [8] (2010) define the concepts and system parameters of underground pipeline transportation systems. The concepts for pipeline transportation include carrier speed, capacity, pipe diameter, track type, transportation distance, etc. Research on the design and selection of technical parameters by Kenneth A. James [9] (2000) and other scholars has explored the use of electromagnetic-driven underground logistics system conceptual design, and established a vehicle solid model that has been validated in a technical experiment. Stein [10] (2011) has proposed the concept of using cargo compartments in an urban ULS (Cargo-Cap), and carried out physical model technology experiments. Ma Chenglin[11] et al. (2016) evaluated the selection of pallets for an urban ULS. An example of the pallet selection for the ULS in general inland cities is given. Goh Anthony TC [12] (2017) combines the Multivariate Adaptive Regression Spline (MARS) method with the Logistic Regression (LR) method. It is considered promising to evaluate the stability of the underground entrance excavations using the MARSLR model; Roop [13-14] (2006) of the Texas Transit Research Institute (TTI) has established the concept of the ULS for the Safe Freight Shuttle and conducted a physical model technique experiment. The pneumatic capsule pipeline (PCP) research is mainly based on Henry Liu [15-16] (2004) in the United States, focusing on the introduction of PCP concepts, dynamic systems, and empirical research. Additional studies include the AGV study in the Netherlands [17] (2002), the Japanese DMT study [18] (2003), and the UK's Mole Urban system [19] (2016) research.

2.2. Feasibility

Japanese scholar Kashima [20] (2003) uses Tokyo as an example to discuss the basic operation methods, cost-effectiveness, and impact on the original logistics system of an urban ULS. M.C.Van der Heijden [21] (2002) simulates and analyzes the operational characteristics of the underground logistics network structure between different regions, and the cost and efficiency are studied in detail. C. Versteegt [22] (2003) proposes the SEP method, which evaluates the intelligent logistics system and its control system. The SEP method has been successfully applied to the evaluation of Schipol's automated guided vehicles and material handling stations in the ULS. Vernimmen Bert, Dullaert Wout [23], et al. (2009) consider that the capacity of the traditional hinterland transportation system lacks the capacity to accommodate the long-term container terminal at the Deurganckdock in Antwerp. They propose the idea of constructing a specialized ULS to transfer containers between two river banks. Berner F, Hermes M [24], etc. (2016) introduce basic principles of the underground logistics circulation in road construction; a summary of research methods for the field is also presented. They conclude that if the transportation capacity is too low, it limits the main construction process and increases the construction costs of roads.

2.3. Layout planning

The network form of an urban ULS directly affects its operational efficiency; it also directly affects the rationality of the system structure, engineering investment, as well as the economic and social benefits after the completion of the network. Research on the network layout of urban underground logistics and node planning has been conducted. Johan Visser[25] (2005) analyzes the characteristics of different network structures such as point, line, and network, and made recommendations on the policy of ULS network construction. Arjan van Binsbergen and Johan Visser[26] (2007) study network optimization methods for logistics optimization layouts. Zhu Jianjun[27]（2007）establishes the location model based on 0-1 linear location-allocation model; Han Song[28]（2010）analyzes the necessity of development of urban underground logistics concerning the situation of urban logistics which has urban characteristics and E-commerce demands. It is proposed that the restriction problem of logistics volume could be solved if the underground logistics nodes and network could be planned through powerful data function of GIS; Ma Cheng-Lin[29]（2013）and other scholars analyze the related transport procedure of underground logistics terminal. Based on two indexes, relativity of two service areas and logistics costs, multiobjective 0-1 mixed integer programming model of logistics nodes layout is established. According to Genetic Algorithm and simulated optimization of Automod software, the final layout is worked out; Li Tong[30]（2016）deems that traditional logistics network has reached the peak in big cities of China and the ground logistics will gradually move underground. In this way, the ground space will be freed up.

2.4. Summary

Through the reading of related literature and online news, it can be concluded that there are many problems in the research of ULS. The main research problems are:

(1) The construction of urban ULS is a very complicated project involving political, economic, environmental, technological, and other related factors. These projects face challenges in the actual implementation process. Therefore, it is necessary to continue to conduct more in-depth research on the urban ULS.

(2) The existing research mainly focuses on the development space and application prospects of vehicles, operational mechanisms, and underground logistics. There is relatively little on underground space planning and empirical research for the urban ULS.

Thus, this paper addresses the problem of urban underground logistics node layout planning by adopting qualitative and quantitative techniques to build and analyze novel planning layout models. The proposed approach is validated using an illustrative example. The contributions of this research may serve as a foundation for the research community to build upon in the future.

3. Foundations of the ULS logistics node layout

The network of a ULS consists of network routes and network nodes, mainly for the distribution, transportation, and storage of goods. The operational efficiency of the entire logistics system, rationality of system, investment in system engineering, economic benefits, and social benefits are closely related to the network form of the logistics system. Therefore, before the construction of the ULS, the network structure needs to be carefully planned according to the future development status and layout structure of the city. Only in this way can we meet the future development requirements of cities.

3.1. Definitions for logistics nodes in a ULS

The ULS network realizes functions of the entire ULS including transportation, storage, marketing, distribution, circulation processing, and information reporting. Graph theory is well-suited to represent the logistics network structure. The ULS network is defined as a proportional directed graph:

$$U=\{N,\ V,W\} \quad (1)$$

In the formula: U - ULS network, where N is a set of logistics nodes, V is a directed network route, and W is the weight, or proportion of the route, including transportation distance, time, cost, etc.

A logistics node is composed of a logistics center and several distribution centers.

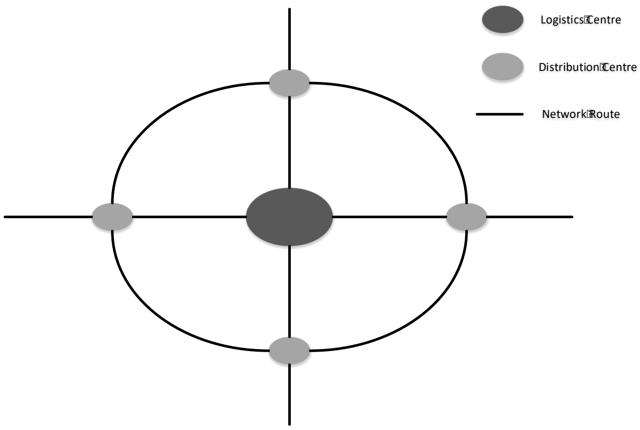

Fig.1 Underground Logistics System Network

The logistics center is the gathering point of the ULS network; it is the hub of its management and control. A logistics center is responsible for transporting goods, operating and managing logistics, controlling and maintaining system delivery vehicles, and ensuring the safety of the entire system. A logistics center is also known as a primary node or a primary transit center.

The distribution centers provide similar functionality to the logistics center, but its composition and operation are much simpler. A distribution center is also known as a secondary node or a secondary transfer center.

The network route refers to the route that connects network nodes, allowing the delivery of goods to the destination. These routes can be a mix of underground and traditional ground connections, depending on the needs of different cities.

Network nodes are not only the hub of the logistics network, but also the backbone of the management and operation of the ULS. Logistics nodes play an important role in the network system to provide cargo transportation. The logistics are planned in two categories: incoming flow and outgoing flow. The incoming flow refers to the goods flowing from different locations in the city into the ULS centers; the outgoing flow refers to the flow of goods from the ULS centers to their destinations.

3.2. Summary of alternative Node layout forms

At present, United States, Germany, Netherlands, Japan, and other developed countries have provided substantial contributions in both research and practice on the network planning of ULS. Many scholars continue to improve various ULS network models, and measure different network layouts by means of the connection index comparison method and other basic data obtained from surveys and calculations. According to different connection forms between the network route and the distribution center and the logistics center, the network layout of the ULS can be described as a wired, ring-shaped, grid-like, tree-like, or mixed layout.

The layout of the network of the ULS can be mainly described as a linear, circular, tree, grid, or hybrid layout structure. The kind of structure reflects the connection mode of the logistics route, logistics center, and distribution center.

Table 1 Network layout structure comparison table

Layout structure	Advantage	Disadvantage
Linear layout structure	Low investment cost, low development difficulty, and large selectivity to nodes	Low connectivity and low transport capacity
Ring layout structure	Low investment costs and low development difficulty	Any problem with one route will affect the connectivity of the entire network.
Tree layout structure	High transportation capacity and high connectivity	High investment cost, difficult development, certain selectivity to nodes, low connectivity
Grid layout structure	Higher transportation capacity and connectivity	Connectivity is lower than grid-like layout
Mixed layout structure	More nodes, high connectivity of the logistics network	High investment costs and difficult development

Different network layouts of ULS are suitable for different situations, each with its own characteristics. In general, a simple network has lower costs, but provides poor flexibility whereas a complex network has good flexibility, but its cost is higher. Therefore, when constructing a network, the advantages of different layout modes should be comprehensively analyzed, and the network layout structure of the ULS should be planned to meet the needs of the local conditions in order to achieve better results.

Since the ULS includes two hierarchical nodes (the logistics center and the distribution center), the network connection mode has two types, depending on the connection conditions of the two hierarchical nodes:

(1) Hierarchical Grade network nodes (e.g., two-level). The distribution center combines the logistics center model. The entire network has a logistics center and several distribution centers, which are connected to each other through underground transportation routes.

(2) The network node is not classified. It is completely connected to the logistics center and the distribution center.

3.3. Node connection method

Considering the specific conditions of a city's cargo circulation, the node connection method of the urban ULS studied in this paper can be described as the direct connection of the logistics centers in different regions. In addition, the distribution center is only directly connected to the logistics center in the region where it is located. The ULS nodes include the out-of-area logistics park and the two-level underground nodes in the area, namely the logistics center and the distribution center. The location in the logistics park has been determined, and the two-level underground logistics nodes need to be planned. The logistics center is connected to the logistics park to transport the cargo underground. The logistics centers can communicate with each other to transport goods across one or more regions. The secondary nodes (distribution centers) and non-local logistics centers must communicate with the regional logistics centers. The distribution center is also connected to the ground transportation system, and ultimately goods are delivered through traditional ground transportation systems. The address of a ULS node comes from the candidate area and has uncertainty, so the node layout model is initially determined according to the regional logistics requirements.

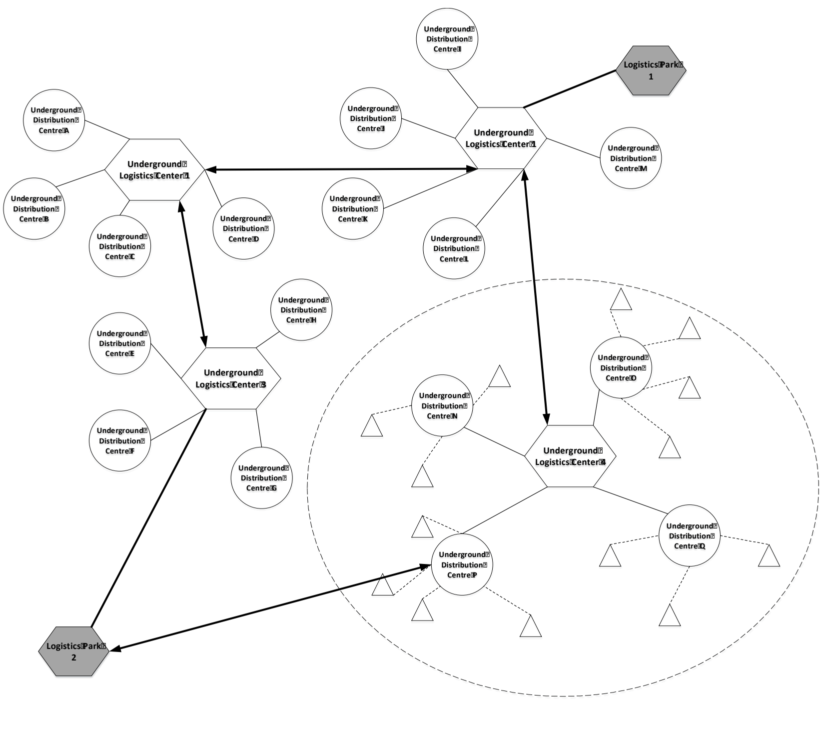

Fig. 2 Schematic diagram of the underground logistics system node layout

4. ULS problem analysis: issues in defining a node layout planning model

4.1. Determining the Layout Model of urban ULS

Selecting the locations of the network nodes of the ULS, including the logistics center and the distribution center, is a key planning decision. These nodes are the transit stations of the underground logistics and their locations are directly related to the effectiveness of the entire logistics system. In the planning, various factors should be considered comprehensively: specific existing conditions of the city; requirements for the safe storage of goods; specific plans for the city; and the need to adapt the system to maintain a reasonable flow of goods. In addition, movement of goods needs to be relatively convenient with good geological, transportation, and terrain conditions; it has a good infrastructure for communication, power supply, water supply, and drainage.

Table 2 Comparison of several location models

	Formula	**Advantage**	**Disadvantage**
Gravity method[31]	$MinC = \sum_{i=1}^{n} f_i V_i d_i$	The model is simpler and easier to solve	Applicable to single-point location, calculate the optimal solution is the theoretical optimal solution, may not meet the actual situation
P-median method[32]	$Z = \min \sum_{i \in N} \sum_{j \in M} d_j c_{ij} y_{ij}$	Less known conditions and simpler modeling	Suitable for discrete location, solving is very difficult
Baum-Wolf model[33]	$\min Z = \sum_{i=1}^{m} \sum_{k=1}^{n} \sum_{j=1}^{l} \left(C_{ik} + C_{kj}\right) x_{ijk} + \sum_{k=1}^{n} v_k \left(Q_k\right)^{\theta} + \sum_{k=1}^{n} F_k r\left(Q_k\right)$	Simpler calculation	Only consider the cost of freight, do not consider fixed construction costs and customer benefits

It can be seen from the above comparison that different location models have different advantages and disadvantages. In this work, we comprehensively consider the actual situation and establish a layout model for urban ULS based on the model presented in Section 3.3.

At present, there are many research results available on the location of traditional logistics distribution centers, in particular on planning the location of multi-target logistics centers. However, the constraints of site selection for these logistics node centers are relatively simple. In contrast, few studies are available on planning the location of underground logistics sites.

The ULS nodes consist of two parts: the logistics center and the distribution center. Therefore, the location problem needs to consider the similarities and differences between the two. The main functions of the logistics center are cargo transportation, cargo transit, and logistics management and operation. It is the center of ULS management and control, and does not carry out terminal distribution. The distribution center is directly connected to the underground logistics center, and cooperates with the above-ground transportation route to realize the terminal distribution function of transporting the freight to the customer. The service area of a logistics center is set to 80 km^2, and the general service range of a distribution center is within 3 km.

The ULS is a new type of logistics system. The ULS of a complete commercial operation has not been built nationwide yet. Therefore, in the actual logistics node location decisions, the existence of competition is not considered, as there are no existing logistics nodes present. Moreover, the urban ULS network is a huge investment and is a relatively long-term, system engineering endeavor. The primary goal is to satisfy the needs of urban commerce, industry, service industry, and citizens, while considering the lowest transportation costs.

4.2. Constructing the Model

4.2.1. Distribution Center Distribution Model

(1) Problem description

The selection of the logistics centers of the urban ULS is a core problem in the creation of the ULS planning layout model. Simply put, a minimum number of these centers need to be set in a certain area to cover all the cargo demand points. In the selection of the logistics nodes, the least number of logistics center needs to be identified, which greatly reduces initial construction investment. In addition, because the cargo operation routes between the logistics nodes are basically underground, between existing urban buildings, this reduces the impact on the ULS construction. Different from the problem of locating above-ground logistics nodes and the shipment of goods, the influence of urban ground space and urban road traffic should be fully considered.

To accomplish this, the aggregate covering model can be used. The set covering problem is one of the integer programming problems in operations research. In the set covering problem, a collection of service equipment is available to provide overlapping services for some devices. The goal is to determine the minimum collection of installed equipment that meets the needs of every device. Its mathematical model was first proposed by Toregas et al[34]. It has been applied, for example, to solve the problem of site selection for emergency service facilities such as fire stations and ambulances.

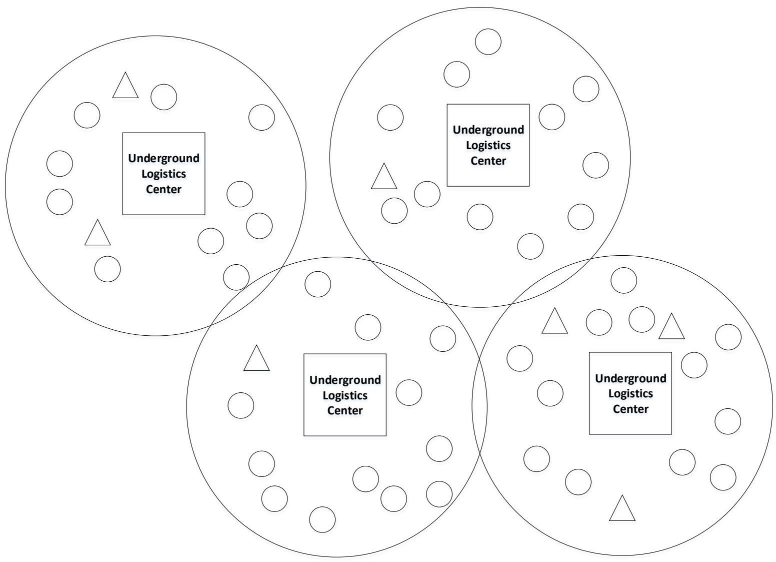

Fig. 3 Schematic diagram of the collection covering model

The use of an aggregate covering model to select the logistics center of the urban ULS sets the corresponding objective function and constraints for the demand points with known requirements. A set of logistics nodes to meet the requirements of these demand points is determined in the model. Hence, the goal of the objective function and constraints is to determine the number and location of logistics centers to be established in order to cover all of the demand points. The solution model is simple, and can be directly realized by LINGO. Therefore, adopting the aggregate covering model to generate this aspect of the urban ULS planning layout model has great advantages.

(2). Symbol setting

Through the above analysis, the relevant parameters of the set covering model are now defined. The specific parameters are as follows:

U means a collection representing demand points;

y_i means the logistics node i;

e_j means the demand point j;

$i \in I$ means that the logistics center i can be a demand point set U_i that provides services.

(3) Model building

a. Objective function

Assume that the collection of all logistics demand points is $U=\{e_1,e_2,...,e_n\}$, $U_1,U_2,...,U_m$, Yes U Subset, if $I\subseteq\{1,2,...,\mathrm{m}\}$ And $\bigcup_{i\subseteq I}U_i=U$, then $U=\{U_i\}_{i\subseteq I}$ Overriding a collection of *U*, meaning that each element in *U* is at least a subset of *U* $U_i\left(i\subseteq I\right)$ Medium U_i Inclusive. The ultimate goal of set covering is to find the smallest base *U* to cover all the elements inside.

For each subset $U_i\left(i=1,2,...m\right)$, introducing decision variables:

$$y_i=\begin{cases}1,\mathrm{i}\in\mathrm{I}\\0,\mathrm{others}\end{cases} \quad (2)$$

Then the set covering model of the 0-1 plan is established as follows:

$$\min\sum_{i=1}^{m}y_i \quad (3)$$

The objective function indicates that the minimum number of logistics nodes is selected.

b. Constraints

$\sum_{i:e_j\in U_i}y_i\geq1, j=1,2,...,n$ $\quad y_i=0,1, i=1,2,...,m$ The first constraint means that each demand point can be covered by at least one logistics node.

The range of values represented by the second constraint is binary. $y_i=1$ indicates that the i^{th} logistics node is selected, whereas $y_i=0$ indicates that the i^{th} logistics center is not selected.

c. Set covering model

According to the above analysis and discussion including the comprehensive consideration of various aspects and determining the relevant constraints, a general model is derived:

$$\min \sum_{i=1}^{m} y_i \quad S.T. \begin{cases} \sum_{I:e_j \in U_i} y_i \geq 1, \ \mathrm{j} = 1,2,...,n \\ y_i = 0,1, i = 1,2,...,m \\ y_i = \begin{cases} 1, & \mathrm{i} \in I \\ 0, & \mathrm{others} \end{cases} \end{cases} \quad (4)$$

4.2.2. Distribution center layout model

(1) Problem description

The selection of the distribution centers of the urban ULS is a second core problem in the creation of the ULS planning layout model. Given there are several distribution service demand points in a certain area, and the demand quantity of the demand points is known, the problem is how to meet the demands while minimizing the total logistics cost. The total cost includes construction, fixed, and distribution costs. Initially, parts of several candidate locations are selected in the general area that needs a distribution center. To simplify the problem, we make the following assumptions:

1) Select a part of the construction distribution center from the known candidate locations;

2) The distribution cost is proportional to the delivery amount;

3) The distribution center can meet the distribution service needs of all demand points;

4) The annual demand for each demand point is known;

5) Assume that the maximum capacity of the logistics center can accommodate the sum of the demand for all demand points;

6) The distribution center does not cross-deliver the demand customer, that is, one demand point is only served by one distribution center.

To accomplish this, a 0-1 model is proposed. An 0-1 model is a special integer model where the decision variables are 0 or 1. It is widely applied in issues concerning the economic management (Wang Yuan, Wen Lan, Chen Mufa, Mathematics Dictionary: Science Press, 2010). The goal of the objective function and constraints is to determine the number and location of distribution centers to be established in order to meet the distribution requirements of the demand points, while minimizing the associated costs.

(2) Symbol setting

Through the above analysis, the relevant parameters of the model are now defined. The specific parameters are as follows:

n - the number of demand points, known parameters;

m - the number of candidate locations in the distribution centers, known parameters;

t - plan to build the number of distribution centers, known parameters;

D - the total annual demand for all demand points, known parameters;

x_j - the quantity of goods delivered by internal demand points in the region j (from within the area), known parameters;

a_{ij} - the distribution rate of the alternative distribution center i to the point of demand j (internal freight rate), known parameters;

b_{ij} - the transportation rate of the logistics center for the region passed the first i distribution center to demand point j (external freight rate), known parameters;

w_j - the amount of cargo of the logistics center to the demand point in the region j (from outside the region), known parameters;

g_i - the amount of cargo in distribution center i;

g_{ij} - the amount of cargo stored in distribution center i to the point of demand j;

F_i - the fixed annual cost of candidate locations, where the distribution center is built in the first i, known parameters;

C_i - management and storage rate of distribution center i, known parameters;

Z - the total logistics costs;

d_i - the distance from the logistics center to the distribution center i, known parameters;

p_i - the unit construction cost of the regional logistics center to the i track of each distribution center, known parameters;

$$y_i = \begin{cases} 1, & \text{build a distribution center at point i, candidate location} \\ 0, & \text{do not build a distribution center at point i, candidate location} \end{cases}$$

(3) Model building

a. Objective function

The objective function is to select candidate positions in an area, with known demand points, to build a distribution center that minimizes the total logistics cost of the entire distribution system. The following 0-1 mixed integer programming layout model is used to represent the problem of multi-distribution center selection with the lowest total cost.

The objective function mainly includes the contents of the following sections:

From the internal distribution of goods, the demand for goods at different demand points is available n dimension vector $X = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & \cdots & x_n \end{bmatrix}^T$. Among them $row\_\min \sum_{i=1}^{m}\sum_{j=1}^{n}(y_i a_{ij})_{M\times N}$ represents a non-zero minimum value for each column. These constitute a new matrix representing the minimum shipping cost incurred by the selected distribution center. This can be expressed as:

$$row\_\min \begin{bmatrix} y_1a_{11} & y_1a_{12} & y_1a_{13} & y_1a_{14} & \cdots & y_1a_{1n} \\ y_2a_{21} & y_2a_{22} & y_2a_{23} & y_2a_{24} & \cdots & y_2a_{2n} \\ y_3a_{31} & y_3a_{32} & y_3a_{33} & y_3a_{34} & \cdots & y_3a_{3n} \\ y_4a_{41} & y_4a_{42} & y_4a_{43} & y_4a_{44} & \cdots & y_4a_{4n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ y_ma_{m1} & y_ma_{m2} & y_ma_{m3} & y_ma_{m4} & \cdots & y_ma_{mn} \end{bmatrix} \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & \cdots & x_n \end{bmatrix}^T \quad (5)$$

From the cost of external goods delivery, the demand for goods at different demand points is available in an n dimension vector $W = \begin{bmatrix} w_1 & w_2 & w_3 & w_4 & \cdots & w_n \end{bmatrix}^T$. Among them $row\_\min \sum_{i=1}^{m}\sum_{j=1}^{n}(y_i b_{ij})_{M\times N}$ represents a non-zero minimum for each column. These constitute a new matrix representing the shipping costs incurred by the final selected transport path of the goods. This can be expressed as:

$$row\_\min\begin{bmatrix} y_1b_{11} & y_1b_{12} & y_1b_{13} & y_1b_{14} & \cdots & y_1b_{1n} \\ y_2b_{21} & y_2b_{22} & y_2b_{23} & y_2b_{24} & \cdots & y_2b_{2n} \\ y_3b_{31} & y_3b_{32} & y_3b_{33} & y_3b_{34} & \cdots & y_3b_{3n} \\ y_4b_{41} & y_4b_{42} & y_4b_{43} & y_4b_{44} & \cdots & y_4b_{4n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ y_mb_{m1} & y_mb_{m2} & y_mb_{m3} & y_mb_{m4} & \cdots & y_mb_{mn} \end{bmatrix}\begin{bmatrix} w_1 & w_2 & w_3 & w_4 & \cdots & w_n \end{bmatrix}^T \quad (6)$$

With respect to the construction costs for distribution centers and tracks, $\sum_{i=1}^{m} y_i F_i$ indicates the construction cost of the distribution center, while $\sum_{i=1}^{m} y_i d_i p_i$ indicates the cost of track construction for the logistics center and the track center.

With respect to the storage and management costs of the distribution center, $\sum_{i=1}^{m} C_i \sum_{j=1}^{n} g_{ij}$ indicates the storage management fee incurred by the quantity of goods passing through the i^{th} distribution center.

b. Constraints

The constraints for this problem are summarized below:

$$\sum_{j=1}^{n} g_j \geq D$$

$$\sum_{i=1}^{m} y_i = t$$

$$\sum_{j=1}^{n} g_{ij} \leq My_i, i = 1, 2, ..., m$$

$$y_i = 0,1; i = 1, 2, .., m$$

$$d_i \geq 0; i = 1, 2, .., m$$

$$a_{ij}, b_{ij} \geq 0; i = 1, 2, .., m, \ j = 1, 2, ..., n$$

$$x_j \geq 0, w_j \geq 0; \ j = 1, 2, ..., n$$

$$g_j = x_j + w_j; \ j = 1, 2, ..., n$$

c. 0-1 planning model

According to the above analysis and discussion, which presents a comprehensive consideration of various aspects and determines the relevant constraints, a general model is derived:

$$\begin{aligned} \min Z = & row\_\min \sum_{i=1}^{m}\sum_{j=1}^{n}\left(y_i a_{ij}\right)_{M\times N} \cdot \sum_{j=1}^{n}\left(x_j\right)_{N\times 1} + \sum_{i=1}^{m} C_i \sum_{j=1}^{n} g_{ij} + \sum_{i=1}^{m} y_i F_i + \sum_{i=1}^{m} y_i d_i p_i \\ & + row\_\min \sum_{i=1}^{m}\sum_{j=1}^{n}\left(y_i b_{ij}\right)_{M\times N} \cdot \sum_{j=1}^{n}\left(w_j\right)_{N\times 1} \end{aligned} \quad (7)$$

The formula indicates that if a candidate distribution center location provides goods to some demand points, a distribution center must be constructed at the candidate location, where M is a very large positive number.

4.3. Calculation based on Bat-inspired Algorithm

Aiming to solve the theoretical distribution center layout models presented in the above two sections, this paper adopts a Bat-inspired Algorithm. The original algorithm has a simple model and is easy to implement; it provides a relatively fast convergence and optimization ability. It has been widely used to solve high-dimensional nonlinear optimization problems and various engineering problems in the real world. The algorithm has been improved since its original introduction.

4.3.1. Introduction to the algorithm

The Bat-inspired Algorithm is a heuristic algorithm proposed by Xin-she Yang[35] based on bat echolocation in 2010. It is an effective method for searching global optimal solutions. It uses the ultrasonic features of the miniature bat and has the following ideal rules:

(1) All bats judge the difference between food and obstacles using the method of echolocation;

(2) At the location x_i, every bat at speed v_i in a random flight takes different wavelengths (or frequencies) f_i) and sound intensity A_i in its search for prey. They automatically adjust the wavelength (or frequency) of the emitted pulse according to the degree of proximity to the target;

(3) Although the pulse loudness varies, it is assumed that the loudness is reduced as the algebra increases from maximum $A_{\max}$ to minimum $A_{\min}$.

The Bat-inspired Algorithm has the characteristics of fast convergence, potential for distribution and parallelism; however, it has problems such as low optimization precision, slow convergence speed, and can easily fall into a local optimum. In order to improve the performance of the Bat-inspired Algorithm, a variety of improved and effective variant Bat-inspired Algorithms have been developed.

The Lévy flight trajectory is a stable distribution proposed by Lévy and described by Benoist-Madelbrot[36]. The Lévy flight is a random walk, and its step size is a continuous heavy-tailed distribution.

In the improved algorithm, the below formula is applied to substitute the speed and location updating pattern of former algorithm.

$$x_i^{t+1} = x_i^t + L(\lambda) \otimes \left(x_i^t - x^*\right) \quad (8)$$

In the formula, x_i^t is the spatial position of the bat in search t . x^* is the position of the best bat of this group. Lévy(λ) represents the random searching vector where step size of the walk is subject to Lévy distribution. λ is scale parameter; $\otimes$ stands for vector calculation.

The basic idea is shown in Fig. 4.

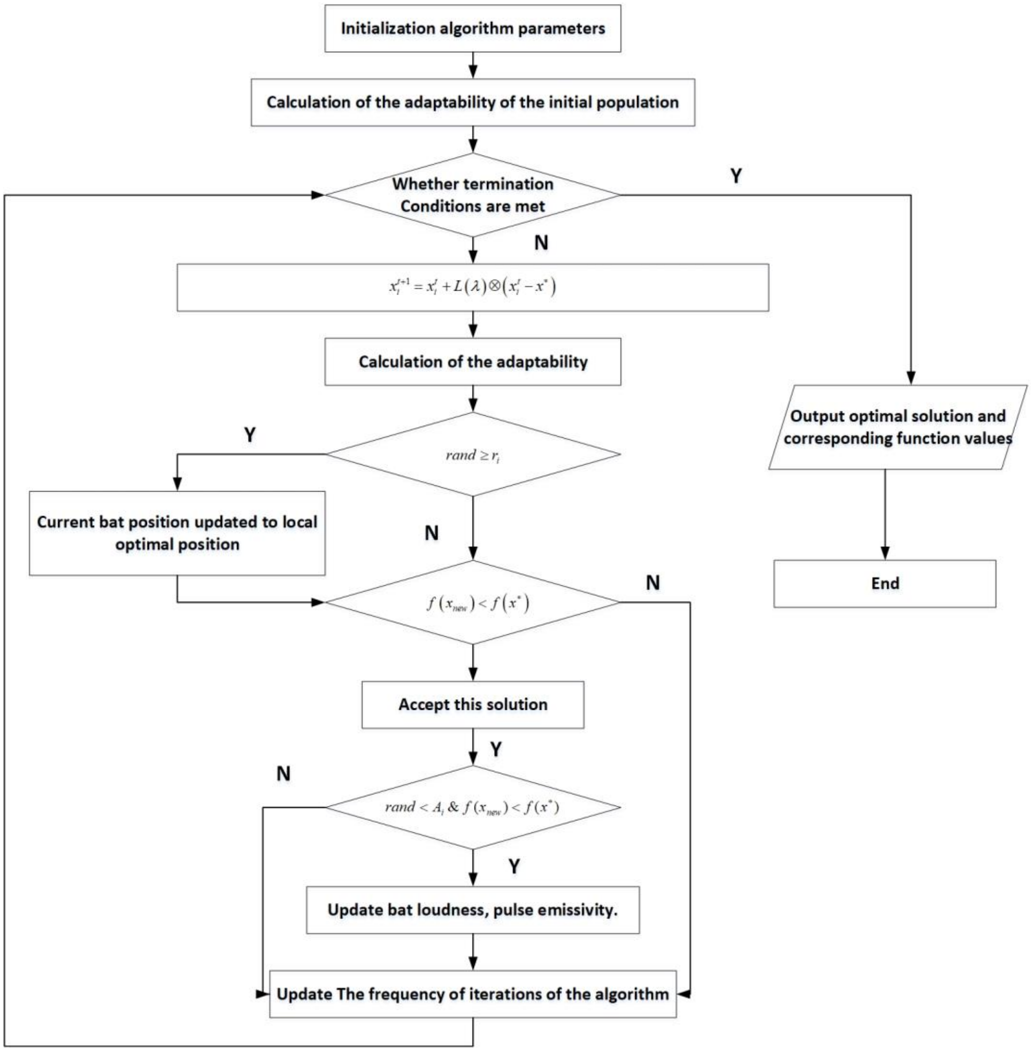

Fig. 4 Flow chart of the Bat-inspired Algorithm based on Levi's improved flight

5. Analysis of the planning layout for the Shanghai ULS

5.1. Logistics Center Determination

This paper studies the location of the urban underground logistics nodes within the central ring road of Shanghai. Fig. 5 shows the set of all of the demand requirements within the planning area.

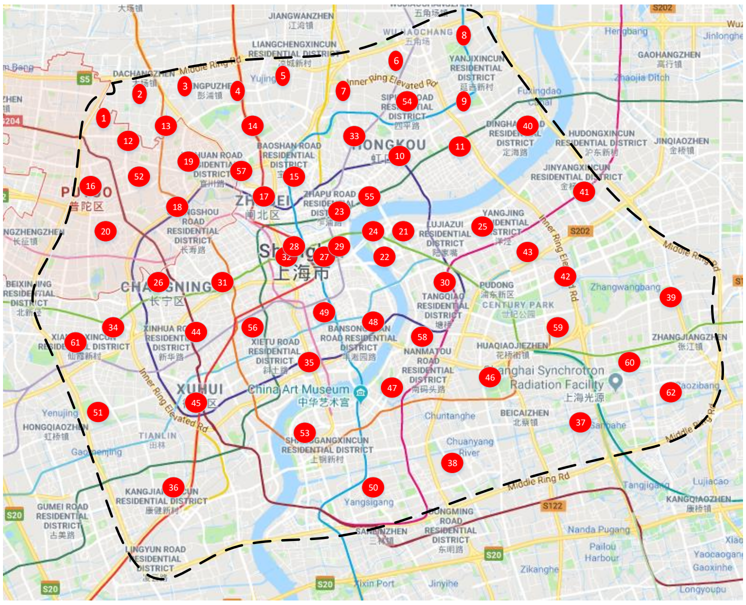

Fig. 5 Distribution of demand points of goods within Shanghai Central Ring Road

Each mark in the figure corresponds to a cargo demand point, and there are 62 freight demand points according to the incomplete statistics available. Each demand point corresponds to a residential area, college, business center, tourist area, office area, and the like.

Considering the geographical location and development, 11 alternative logistics centers are selected for consideration. The alternative logistics centers are:

Logistics Center 1: Guohua Logistics Shanghai Spare Parts Center

Logistics Center 2: Luolei Industrial Company Logistics Center

Logistics Center 3: Shanghai Speed Logistics Center

Logistics Center 4: Deppon Logistics Center

Logistics Center 5: DHL Express Center

Logistics Center 6: Pudong Charity Supermarket Logistics Center

Logistics Center 7: Shanghai Nanbei Logistics Center

Logistics Center 8: Shanghai Linghua Logistics Center

Logistics Center 9: China Salt Logistics Center

Logistics Center 10: Heuer Optics East China Logistics Center

Logistics Center 11: Shanghai Jiadeli Supermarket Logistics Center

Fig. 6 illustrates the distribution of goods supply points and demand points in the planned area of Shanghai. The collection of these points is the set of underground logistics center points and demand points of goods within the Shanghai Central Ring Road.

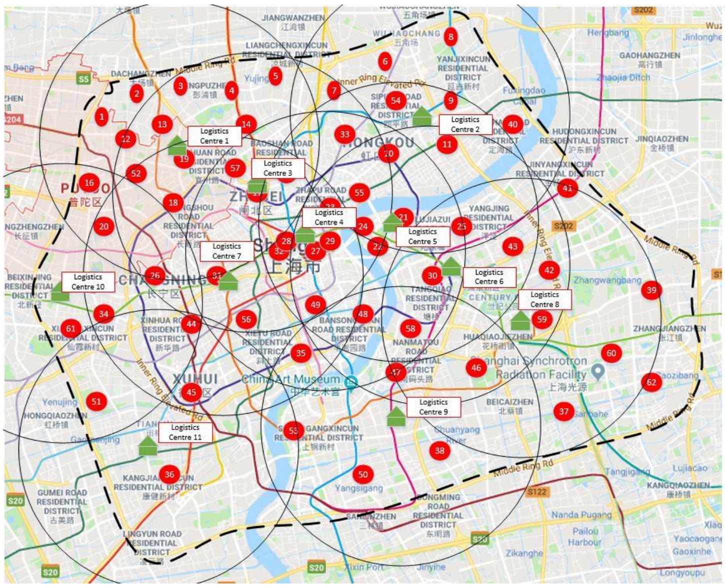

Fig. 6 Alternative Logistics Center Service Coverage

The set of independent variables of the set covering model, i.e., the point set of the underground logistics center, is recorded as $X=\{x_1,x_2,x_3\cdots,x_m\}$, (m=11).

The set of dependent variables of the set covering model, i.e., the set of demand points, is denoted as $U=\{u_1,u_2,u_3\cdots,u_n\}$, (n=62).

This paper sets an underground logistics center service area of approximately 80km^2. According to the distribution map of the Shanghai underground logistics center and cargo demand points, we can compute the supply matrix of the Shanghai underground logistics center point to demand point, which is shown as follows.

$$A=\begin{bmatrix} A_1 \\ A_2 \\ A_3 \end{bmatrix}$$

And

$$A_1=\begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&0&0&0&0&0&0&0\\
1&0&1&0&0&0&0&0&0&0&0\\
1&0&1&0&0&0&0&0&0&0&0\\
1&0&1&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0\\
0&1&1&0&1&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0\\
0&1&0&1&1&1&0&0&0&0&0\\
0&1&0&0&1&1&0&0&0&0&0\\
1&0&1&0&0&0&0&0&0&0&0\\
1&0&1&0&0&0&0&0&0&0&0\\
1&0&1&1&0&0&0&0&0&0&0\\
1&0&1&1&1&0&1&0&0&0&0\\
1&0&0&0&0&0&0&0&0&1&0\\
1&0&1&1&1&0&1&0&0&0&0\\
1&0&1&1&0&0&1&0&0&0&0\\
1&0&1&0&0&0&1&0&0&0&0\\
1&0&0&0&0&0&1&0&0&1&0
\end{bmatrix}
A_2=\begin{bmatrix}
0&1&0&1&1&1&0&0&0&0&0\\
0&0&1&1&1&1&0&0&0&0&0\\
0&1&1&1&1&1&1&0&0&0&0\\
0&1&1&1&1&1&0&0&0&0&0\\
0&1&0&1&1&1&0&1&0&0&0\\
0&0&1&0&0&0&1&0&0&1&0\\
0&0&1&1&1&1&1&0&0&0&0\\
0&0&1&1&1&1&1&0&0&0&0\\
0&0&1&1&1&1&1&0&0&0&0\\
0&0&0&1&1&1&0&1&0&0&1\\
0&0&1&1&0&0&1&0&0&0&0\\
0&0&1&1&1&0&1&0&0&0&0\\
0&1&1&1&1&0&0&0&0&0&0\\
0&0&0&0&0&0&1&0&0&1&1\\
0&0&0&1&0&0&1&0&1&0&0\\
0&0&0&0&0&0&0&0&0&0&1\\
0&0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0\\
0&0&0&0&0&0&0&1&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&1&0&1&0&0&0
\end{bmatrix}
A_3=\begin{bmatrix}
0&0&0&0&0&1&0&1&0&0&1\\
0&1&0&0&1&1&0&1&0&0&0\\
0&0&0&0&0&0&1&0&0&1&1\\
0&0&0&0&0&0&1&0&0&0&1\\
0&0&0&0&0&1&0&1&1&0&0\\
0&0&0&0&0&1&0&1&1&0&0\\
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0&0&1&1&1&1&1&0&0&0&0\\
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0&0&0&0&0&0&0&0&0&1&1\\
1&0&1&0&0&0&1&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&1\\
0&1&0&0&1&0&0&0&0&0&0\\
0&1&1&1&1&1&0&0&0&0&0\\
0&0&1&1&0&0&1&0&0&0&0\\
1&0&1&1&0&0&1&0&0&0&0\\
0&0&0&1&1&1&0&1&1&0&0\\
0&0&0&0&0&1&0&1&0&0&0\\
0&0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&1&1\\
0&0&0&0&0&0&0&1&0&0&0
\end{bmatrix}$$

The location of the distribution center could be determined based on the covering model. Below is the code of LINGO

$$\min = X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 + X10 + X11;$$

$$X1 > 1;$$

$$X2 + X3 > 1;$$

$$X2 > 1;$$

$$X2 + X3 + X5 > 1;$$

$$X2 + X4 + X5 + X6 > 1;$$

$$\cdots \quad \cdots \quad \cdots$$

$$@bin(X1); @bin(X2); @bin(X3); @bin(X4); @bin(X5); @bin(X6); @bin(X7);$$
$$@bin(X8); @bin(X9); @bin(X10); @bin(X11);$$

Run the code and the results are as follows:

```
Solution Report - LINGO1
Global optimal solution found.
Objective value:                              6.000000
Objective bound:                              6.000000
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                             0


                      Variable           Value        Reduced Cost
                            X1        1.000000            1.000000
                            X2        1.000000            1.000000
                            X3        1.000000            1.000000
                            X4        0.000000            1.000000
                            X5        0.000000            1.000000
                            X6        0.000000            1.000000
                            X7        0.000000            1.000000
                            X8        1.000000            1.000000
                            X9        1.000000            1.000000
                           X10        0.000000            1.000000
                           X11        1.000000            1.000000

                           Row    Slack or Surplus      Dual Price
                             1        6.000000           -1.000000
                             2        0.000000            0.000000
                             3        1.000000            0.000000
                             4        0.000000            0.000000
                             5        1.000000            0.000000
                             6        0.000000            0.000000
```

Fig. 7 The output result of LINGO

The results of the covering model show that at least six logistics center points are needed to fully cover the demand for goods at the demand point in the inner area of Shanghai Central. These six logistics centers are the logistics center nodes in the ULS line network of the region, and their distribution is shown in Fig. 8

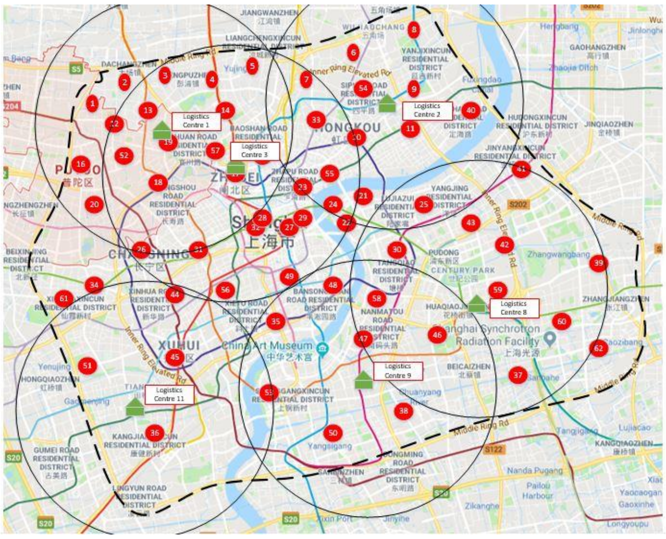


Fig. 8 Logistics Center Selection Results

5.2. Distribution Center Determination

The scope of the logistics center covers the demand for goods at known demand points. Some of the demand points are covered by two or more logistics service centers at the same time. When considering the construction of a distribution center, the construction cost of the underground logistics track needs to be considered, and the setting should be based on the principle of proximity. That is to say, when planning a distribution center, each demand point is allocated according to its distance from the underground logistics center. The demand point is allocated to the service center of the logistics center which is closer to the logistics center.

After selecting the site for the underground logistics center according to the demand, the data-based quantitative analysis can accurately determine the location of an underground logistics distribution center. Regardless of the competition between the new and old logistics distribution centers, the following values (because they cannot be counted) are assumed, and actual statistics are used in this study. In the example of location selection of the distribution center, this paper takes the location of the distribution center within the service center of the logistics center as an example. Based on the improved heuristic Bat-inspired Algorithm, the distribution center is selected by the 0-1 planning model.

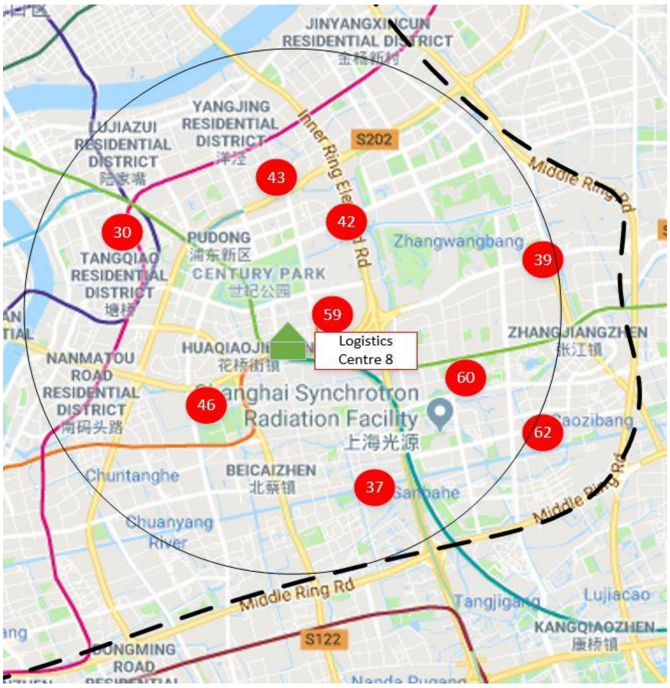


Fig. 9 Alternative Distribution Center Site Planning Plan

As illustrated in Fig. 9, there are nine demand points within the service scope of the underground logistics center 8, and their serial numbers are 30, 37, 39, 42, 43, 46, 59, 60, 62. According to the geographical conditions, location status, and other related factors near the Longyang Road subway station, the locations of the four alternative distribution centers are determined. Ultimately, three distribution centers are selected to achieve the lowest construction cost.

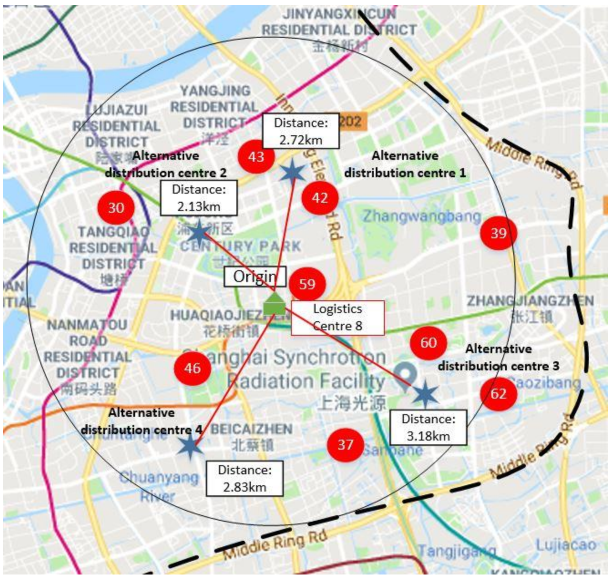


Fig. 10 Alternative Distribution Center (hexagonal representation)

Compared with the location selection of the above-ground logistics nodes, the connection mode of the underground logistics nodes has a number of distinct characteristics. In the urban ULS network, the logistics centers (first-level nodes) in different regions are directly connected by rail, and the underground distribution centers in each region are directly connected to the logistics centers in the region without cross-connection. Therefore, when considering the demand for freight at a demand point, the volume of freight from both inside and outside the region should be considered separately. As specified in this article, a demand point is served by one distribution center. The selection of a distribution center may affect the distribution channels of goods. Therefore, in order to achieve the ultimate goal of the lowest construction cost, the impact of the choice of the distribution center on the cost of the distribution route of the goods should also be considered separately. The results are presented in Table 3, Annual demand for each demand point (from the outside), Table 4, Annual demand for each demand point (from the internal), Table 5 Transportation costs from each candidate point to the demand point (yuan/ton), and Table 6 Underground logistics center 8 to the point of demand for transportation costs (yuan/ton) (in different cases).

Table 3 Annual demand for each demand point w_j (from the outside)

Demand point number	**Annual demand / 10,000 tons**	**Demand point number**	**Annual demand / 10,000 tons**	**Demand point number**	**Annual demand / 10,000 tons**
30	0.67	42	0.79	59	0.84
37	0.94	43	1.05	60	0.78
39	0.82	46	0.69	62	0.90

Table 4 Annual demand for each demand point x_j (from the internal)

Demand point number	**Annual demand / 10,000 tons**	**Demand point number**	**Annual demand / 10,000 tons**	**Demand point number**	**Annual demand / 10,000 tons**
30	0.12	42	0.24	59	0.24
37	0.18	43	0.09	60	0.28
39	0.21	46	0.19	62	0.20

Table 5 Unit transportation costs from each candidate point to demand point (yuan/ton) (internal)

Alternative point Demand point	**30**	**37**	**39**	**42**	**43**	**46**	**59**	**60**	**62**
1	64.09	104.2	74.00	66.54	44.23	80.24	50.11	62.32	130.23
2	46.36	92.99	118.32	62.85	54.44	48.68	58.11	94.32	130.88
3	108.35	64.12	78.77	92.68	134.01	110.12	72.98	49.21	54.97
4	86.08	68.36	138.98	106.32	109.09	58.14	76.33	89.99	94.12

Table 6 Unit transportation costs from each alternative point to demand point (yuan/ton) (external price)

Alternati	**30**	**37**	**39**	**42**	**43**	**46**	**59**	**60**	**62**

ve point Demand point									
1	75.01	113.21	83.68	76.54	54.78	89.74	60.02	72.32	141.23
2	56.38	101.78	126.87	71.95	62.13	59.23	64.89	105.12	139.88
3	117.12	74.25	85.54	101.28	142.01	119.58	81.57	59.32	65.01
4	95.99	78.32	149.01	115.14	118.82	68.14	85.58	97.21	104.12

In addition to considering the flows of goods to and from different regions, it is also necessary to consider the unit storage and management costs, annual fixed costs, construction costs, etc. of each alternative distribution center. As the current research on urban underground logistics systemization is still in the early stage of development, the relevant standards for the cost and cost of the underground logistics center have not reached the mature stage, and different cities have certain differences. Therefore, the relevant data in this paper is based on published research results and academic reports. Considering that the construction cost of underground logistics is high, the distribution center and track construction are converted into a 40-year cycle, thereby weakening the direct impact of excessive construction costs on the site selection results. The construction of urban ULS nodes and pipelines is developed deep below the ground. According to the description of rail construction costs in Chapter 3 it is estimated that the construction cost of an orbit is 300 million yuan per kilometer, and the construction of two-way orbit is planned.

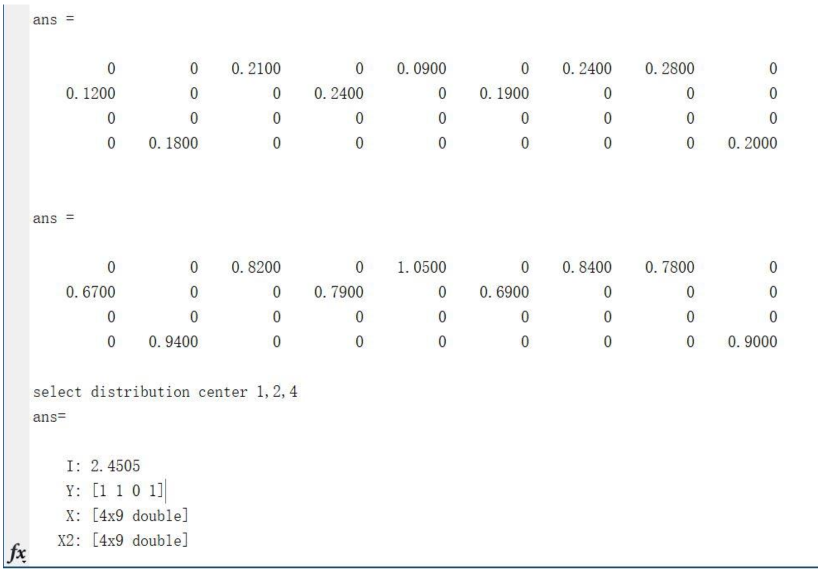
Table 7 Related fees for each alternative distribution center

Alternative distribution center	Unit storage and management fees (10,000 yuan / ton)	Annual fixed fee (10,000 yuan)	Default construction cost (10,000 yuan)	Maximum processing capacity (10,000 tons / year)
1	1.84	42	10152.25	3.50
2	1.65	38	9936.78	3.50
3	1.74	44	10007.19	3.50
4	1.78	39	9997.54	3.50

Table 8 Distance from Logistics Center 8 to each alternative distribution center

	Alternative Distribution Center 1	Alternative Distribution Center 2	Alternative Distribution Center 3	Alternative Distribution Center 4
Underground Logistics Center 8	2.72 km	2.13 km	3.18 miles	values have held relatively steady km

The improved Bat-inspired Algorithm is developed and executed in the MATLAB 2014a environment. The parameters of the new proposed algorithm are set to: $n=10$, $\alpha=0.99$, $\gamma=0.01$, $f_{\min}=0$, $f_{\max}=0.01$, initial loudness $A_0=0.25$, and the initial pulse emissivity $R_0=0.25$. The simulation experiment platform consists of the Window10 operating system, Intel processor 2.40GHz, installed memory is 2.00GB, and the simulation software is MATLAB 2014a. Run the program in MATLAB and the result is as follows: (program is enclosed in the appendix)



```
ans =

         0         0    0.2100         0    0.0900         0    0.2400    0.2800         0
    0.1200         0         0    0.2400         0    0.1900         0         0         0
         0         0         0         0         0         0         0         0         0
         0    0.1800         0         0         0         0         0         0    0.2000


ans =

         0         0    0.8200         0    1.0500         0    0.8400    0.7800         0
    0.6700         0         0    0.7900         0    0.6900         0         0         0
         0         0         0         0         0         0         0         0         0
         0    0.9400         0         0         0         0         0         0    0.9000

select distribution center 1,2,4
ans=

    I: 2.4505
    Y: [1 1 0 1]
    X: [4x9 double]
   X2: [4x9 double]
```

Fig. 11 The result shown in MATLAB

When selecting among the alternative distribution centers identified as 1, 2, and 4, these provide the most feasible distribution center location solutions. At this time, the total construction cost of the distribution center within the service scope of the logistics center 8 is also the minimum cost of 652.413 million yuan. The specific distribution center service objects and delivery quantities are shown in the table below.

Table 9 The volume of goods transported by each distribution center to each demand point (10,000 tons)

Demand point delivery center	30	37	39	42	43	46	59	60	62	Total amount
1	0	0	1.03	0	1.14	0	1.08	1.06	0	3.25
2	0.79	0	0	1.03	0	0.88	0	0	0	2.70
4	0	1.12	0	0	0	0	0	0	1.1	2.22

As can be seen from the above table, when the planned distribution centers identified as 1, 2, 4 form the underground logistics distribution center to be constructed. The demand objects of the distribution center 1 are 39, 42, 43, 59; the demand objects of the distribution center 2 are 30, 42, and 46; the demand objects of the distribution center 4 are 37, 62. The annual shipping volumes for each distribution center are 32,500, 27,000 and 22,200 tons respectively.

5.3. Evaluation based on the layout method of Shanghai ULS

Since the logistics center is connected with the logistics park to realize the underground transportation of goods, the logistics centers can communicate with each other to transport goods across the area. The secondary nodes (distribution centers) and the non-local logistics centers must be connected through the regional logistics centers. The example in this chapter only takes the layout planning of the distribution center in the area where the logistics center 8 is located as an example, and carries out an example analysis of the algorithm and the model application process. Therefore, all the distribution centers within the central region are not completely planned. For the five major logistics parks in Shanghai, direct connection with the planned logistics center can be established to realize the transportation of goods.

For the selected collection covering model of the logistics center, a minimum number of logistics centers are set in a certain area to cover all the demand points of goods. In the selection of the logistics nodes for an urban ULS, the least number of logistics centers can be determined, which greatly reduces the initial construction investment; the model is relatively simple and has certain advantages.

This paper introduces a new heuristic algorithm, an improvement of the Bat-inspired Algorithm, for solving the layout model of the underground logistics distribution center. It is much better compared to the particle swarm algorithm and the basic Bat-inspired Algorithm. The improved Bat-inspired Algorithm and the basic Bat-inspired Algorithm are used to solve the logistics center location calculation examples separately in comparative experiments. For the sake of fairness, the same parameters are taken for both Bat-inspired Algorithm and Lévy's Bat-inspired Algorithm. The function convergence comparison chart is as follows:

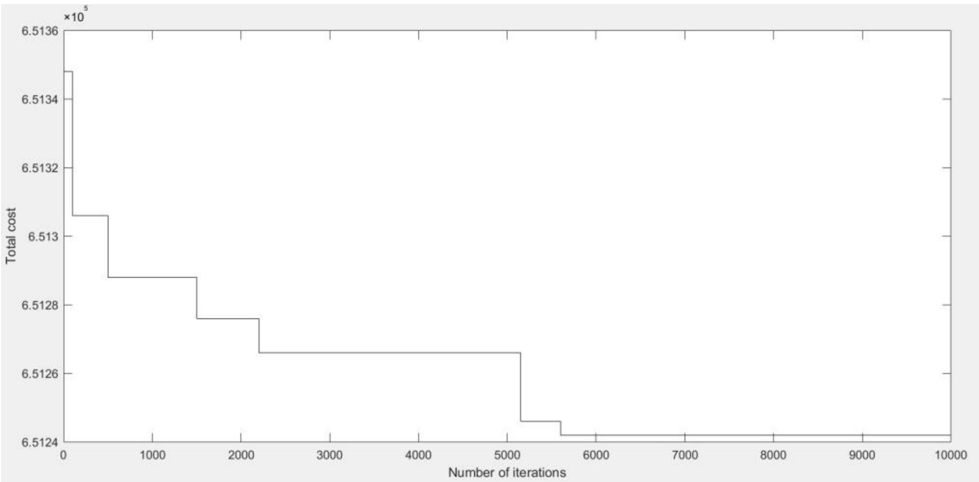


Fig. 12 Bat-inspired Algorithm running results (not improved)

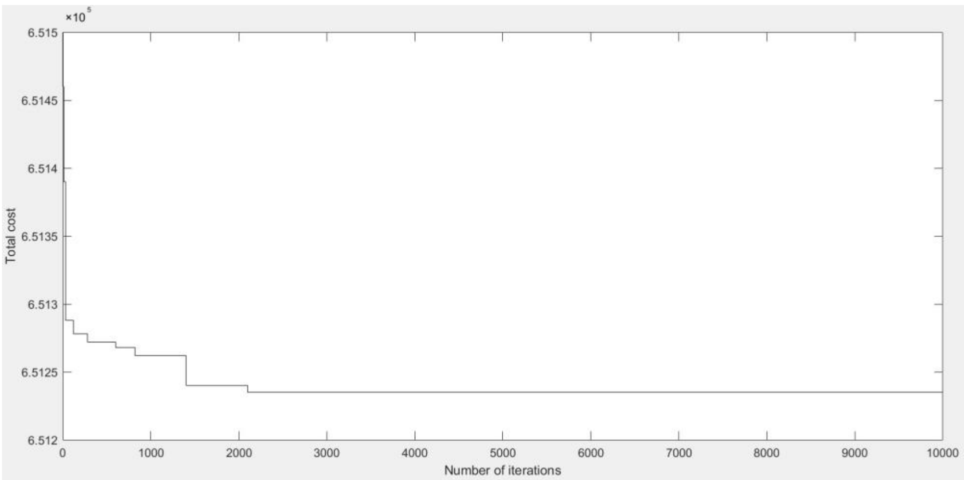


Fig. 13 Improved Bat-inspired Algorithm running results

It can be seen from the above convergence graph that the improved Bat-inspired Algorithm can quickly find the optimal solution in this experiment. The improved Bat-inspired Algorithm converges faster than the basic Bat-inspired Algorithm and can find the optimal solution more quickly. Therefore, it can be inferred that the improved Bat-inspired Algorithm has the potential to solve site selection problems in a more effective manner, and has certain advantages in optimization.

6. Summary

This paper studies the node layout planning problem of an urban ULS and proposes two new models (the logistics and distribution center layout models), and proposes an improved Bat-inspired Algorithm to solve the high-dimensional distribution center layout model problem. Finally, taking the urban underground logistics node system layout planning in the Central District of Shanghai as a case study, the logistics center layout planning and distribution center layout planning models are obtained.

The theoretical method proposed in this paper provides a new perspective and method for the layout planning of urban ULS. At the same time, the improved Bat-inspired Algorithm can be applied to other facilities layout planning problems besides the distribution of underground logistics distribution centers, providing a new solution for similar researches.

7. References

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Appendix

MATLAB main function code of Improved Bat-inspired Algorithm: (partial code)

```
function [best,fmin,N_iter]=bat_algorithm_opt(para)

% Default parameters
if nargin<1,  para=[10 0.25 0.5 ];  end
n=para(1);      % Population size, typically 10 to 25
A=para(2);      % Loudness  (constant or decreasing)
r=para(3);      % Pulse rate (constant or decreasing)

alpha  = 0.99;
gama   = 1e-2;
% This frequency range determines the scalings
Qmin=0;         % Frequency minimum
Qmax=0.1;         % Frequency maximum
% Iteration parameters
tol=10^(-5);    % Stop tolerance
MaxIter = 1e4;
N_iter=0;       % Total number of function evaluations

% Initial arrays
Q=zeros(n,1);   % Frequency
% Initialize the population/solutions
for i=1:n,
   [Sol{i},V{i}]=InitGen;
   Fitness(i) = FeesCal(Sol{i});
end
% Find the current best
[fmin,I]=min(Fitness);
best=Sol{I};

% ======================================================  %
% Note: As this is a demo, here we did not implement the  %
% reduction of loudness and increase of emission rates.   %
% Interested readers can do some parametric studies       %
% and also implementation various changes of A and r etc.  %
% ======================================================  %

% Start the iterations -- Bat Algorithm
rr = 1;
kk = 0;
while (N_iter<MaxIter)
   % Loop over all bats/solutions
   for i=1:n,
      Q(i)=Qmin+(Qmin-Qmax)*rand*rr;
      [SNew{i},V{i}] = BatFly(Sol{i},best,V{i},Q(i));
```

```
        % Pulse rate
        if rand>r
            SNew{i} = Batturb(Sol{i},0.1,0.01);
        end

        % Evaluate new solutions
        FitnessNew = FeesCal(SNew{i});

        % If the solution improves or not too loudness
        if (FitnessNew<=Fitness(i)) && (rand<A) ,
            A = alpha*A;
            kk = kk+1; rr = (1-exp(-gama*kk));
            Sol{i}=SNew{i};
            Fitness(i)=FitnessNew;
        end

        % Update the current best
        if FitnessNew<=fmin,
            best=Sol{i};
            fmin=FitnessNew;

        end

        N_iter=N_iter+1;
        FitnessRecode(N_iter) = fmin;
    end
end

figure(1);
plot(FitnessRecode);
xlabel('Number of iterations ');
ylabel('Total cost');

clc;
Index = find(best.Y~=0);
best
best.Y
best.X
best.X2
fprintf('select distribution center%d,%d,%d\r\n\r\n',Index(1),Index(2),Index(3));
end
```