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Research on monoline channel and sibling terminal layout method of urban underground logistics

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Abstract. The monoline channel and sibling terminal layout method of urban underground logistics is different from the ground logistics node location. Firstly, its model involved construction cost of channel and terminal, the scope of radiation network and response ability of customer demand. Then the solution method and the solving process were given to calculate the scale and layout of the underground logistics terminal and the channel structures among the terminals. Finally, an example was verified that the proposed method was effective and that multi objective specific weight played a key role in affecting the distribution structure of monoline channel and sibling terminal layout of urban underground logistics.

Key words. Underground logistic, channel, modeling, layout.

1. Introduction

The facilities layout of urban underground logistics system are mainly terminal and channel layout. The monoline channel and sibling terminal layout was used in many countries, its terminal and channel settings were mutually affected and they were different from the ground facility location[1–7]. To solve the monoline channel and sibling terminal layout problem of urban underground logistics was helpful to plan and build underground logistics network, and can better reflect the comprehensive benefits of underground logistics. The underground logistics channel directly connected between the underground logistics terminals. There was only one path connected between any two terminals[1,6]. Its layout problem was to determine

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the underground logistics network to serve the entire customers based on the spatial distribution of customers and differentiated customer service index in order to solve the shape of underground logistics network, terminal quantity, terminal services range, terminal location, underground logistics channel structure[7]. According to the service range of terminal, customers could be divided into different regions. The control points of these regions were terminal locations.

2. Model

According to the relation of planning goal, restriction condition and solving variable, the monoline channel and sibling terminal layout model of urban underground logistics should be a multi-objective nonlinear constrained optimization model. The mathematical model was as follows:

$$f^1(x) = \max\left[\frac{1}{n}\sum_{l\in L}\left(\frac{1}{n_j}\sum_{j\in I_l}\left\{\frac{\theta_j}{d_{lj}}\,|j\in N_j\right\}\right)\right] \tag{1}$$

$$f^2(x) = \min\left[nC_{b\mathrm{T}}+C_{bC}D\left(W^{(n)}\right)\right] \tag{2}$$

s.t.$2 \le n \le n_c$; $2 \le n_j \le n_c$; $0 \le nC_b + C_{bC}D\left(W^{(n)}\right) \le C_b^{\max}$;

$\max\left\{\frac{1}{n_j}\sum_{j\in I_l}\{d_{lj}\,|j\in N_j\}\right\} \le d_{\max}$

Where $d_{lj} = \begin{cases} |x_l - x_j| + |y_l - y_j|, d_{lj} \ge d_{\min} \\ M_{\min}, d_{lj} < d_{\min} \end{cases}$

$C_b^{\max}$: Maximum construction cost;n_c:Customer quantity.

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d_{lj}: The urban distance between the underground logistics terminal and the customer:

$$d_{lj} = \alpha_j\left(|x_l - x_j| + |y_l - y_j|\right)$$

x_l, y_l:The Vertical and horizontal ordinate of terminal l ;

θ_j: Customer's two-way comprehensive evaluation value;

α_j: Road detour factor between terminal l and customers j;

n, n_c, n_j: Terminal number; The total of clients; Number of clients severed by terminal j;

C_{bT}, C_{bC}: Terminal Construction cost; Channel construction cost;

$D\left(W^{(*)}\right)$: Total length of underground logistics channel.

The monoline channel and sibling terminal layout model of urban underground logistics was multi objective function. $f^1(x)$was the benefit function, and $f^2(x)$was the cost function. In order to transform into a single objective function, 3 polynomial properties were standardized. Let $\omega_1, \omega_2, \omega_3$were 3 objective functions weights in order to analyze influence of each planning objectives. The objective function of the monoline channel and sibling terminal layout model of urban underground logistics was transformed into:

$$\min f(x) = \omega_3 \frac{n}{\sum_{n=2}^{n_c} n} + \omega_2 \frac{\sum_{(T_i,T_j)\in\mu} l_{ij}}{\sum_{n=2}^{n_c} \sum_{(T_i,T_j)\in\mu} l_{ij}} - \omega_1 \frac{\frac{1}{n}\sum_{l=1}^{n}(\frac{1}{n_j}\sum_{j=1}^{n_j}\left\{\frac{\theta_j}{d_{lj}}\left|j\in N_j\right.\right\})}{\sum_{n=2}^{n_c}\frac{1}{n}\sum_{l=1}^{n}(\frac{1}{n_j}\sum_{j=1}^{n_j}\left\{\frac{\theta_j}{d_{lj}}\left|j\in N_j\right.\right\})} \tag{3}$$

3. Algorithm design

Step1: n underground logistics customer coordinates were standardized, so that the coordinates falled in the [0~1,0~1] coordinate system, the position matrix was $X_{n\times 2}$. Establish the customer comprehensive evaluation matrix $Y_{1\times n}$ and set the initial value$\omega_1, \omega_2, \omega_3$.

Step2: clustering customers based on distances. Establish the initial distance matrix$D^{(0)} = [d_{ij}]_{n\times n}(i, j = 1, 2, \cdots, n)$.when i=j , $d_{ii} = 0$. It was looked for the smallest elements without diagonal elements. If the minimum element was the distance between $X_i^{(b)}$and $X_j^{(b)}$, they were merged into a new class$X_{ij}^{(b+1)}$. A new class was built here $X_1^{(b+1)} X_2^{(b+1)} \cdots X_m^{(b+1)}$.And then $D^{(b+1)}$was found.

$$D_{A,B} = \frac{1}{n_a n_b}\sum_{i=1}^{n_a}\sum_{j=1}^{n_b} d_{ai,bj}, x_{ai} \in \{x_{a1}, \cdots, x_{an_a}\}, x_{bi} \in \{x_{b1}, \cdots, x_{bnb}\}$$

where, $d_{a,b}$was the distance between the samplex_a in the class$A$ and the samplex_b in the class$B$;

$n_a n_b$ were the number of the samplex_a in the class$A$ and the samplex_b in the class$B$; $D_{A,B}$was the distance between the class$A$ and the class$B$

Step3: make b=b+1, jump to step 2, repeat calculation and merge, all the customers could eventually be clustered into one class.

Step4: the initial cluster number was Ncluster, and the interception cluster was obtained. The position matrix of Ncluster underground logistics terminals, underground logistics terminal $\mathrm{l}_{nj\,2}$ and Ncluster cluster.

Step5: when customers each cluster number lt was less than 2 or

$$\max\left\{\frac{1}{n_j}\sum_{j=1}^{n_j}\left\{Dtc_{jl}\left|j\in N_j\right.\right\}\left|l = 1, 2, \cdots, n\right.\right\} \le d_{\max}$$

, make $Ncluster = Ncluster + 1$and return to step 4, otherwise, calculate dt_{ij}. When $dt_{ij} \le 0.01$, the quotient p_{ij}between comprehensive evaluationq_j of customer j became into $p_{ij} = q_j \times M$. Based on taking the time to calculate the range of dt_{ij}, M was 100. Finally, the p_{ij}average values $Cd\,(i) = sum(p_{ij})/lt$ of clusters $idu$and the average values$Cd1\,(Ncluster) = sum\,(C')\,/Ncluster$ of $Ncluster$clusters were obtained.

Step6: Based on the improved genetic algorithm, the shortest length $Cd2\,(Ncluster)$

of $Ncluster$ underground logistics terminals was calculated. The matrix $G_{3\times\left(\frac{(n^2-n)}{2}\right)}$ was constructed, and its arbitrary vector$g_{3\times 1} = [i, j, d_{ij}]$, where i, j was the i, j logistics terminal, $d_{ij}$was the distance from the underground logistics terminal i to the underground logistics terminal j. d_{ij} would be arranged from large to small, sorted to get$G^{'}$.

Step7: find the edge d_{ij} which was the largest distance from the third line of $G^{'}$and it did not affect the path connectivity after the deletion. Otherwise, select the next side.

Step8: repeat step 7 until $G^{'}$ had only n-1 edges. Find minimum path length$Cd2$) and make $Cd3\left(Ncluster\right) = Ncluster$.

Step9: search minimum value of vector$O$, $O = \omega_2 \frac{Cd2}{sum(Cd2')} + \omega_3 \frac{Cd3}{sum(Cd3')} - \omega_1 \frac{Cd1}{sum(Cd1')}$, if the minimum value was 0, it was needed to determine the vector of null values or calculated values, null case gave up, and find the minimum value in the positive element O

Step10: output the location coordinates of underground logistics terminal and the layout of underground logistics network.

4. Example analysis

Suppose that 200 customers from the city logistics customers were chosen as the customers of the underground logistics. Their relative coordinates and the comprehensive evaluation value were shown in Table 1. As shown in Fig. A of Fig 4.

Table 1. Part of coordinates of the underground logistics customers

C	X axis	Y axis	θ	C	X axis	Y axis	θ
$C1$	0.238	0.469	0.035	$C181$	0.013	0.427	0.594
$C20$	0.918	0.743	0.317	$C199$	0.457	0.343	0.290
$C21$	0.702	0.141	0.212	$C200$	0.370	0.243	0.185

To solve the model results were shown in Fig. 1, where Fig.A was the client area bitmap, Fig.B was the client and the underground logistics terminal distribution map, Fig.C was a bitmap underground logistics terminal area, Fig.D was underground logistics terminal network figure.

Table 2. Calculation results with different weight ratios

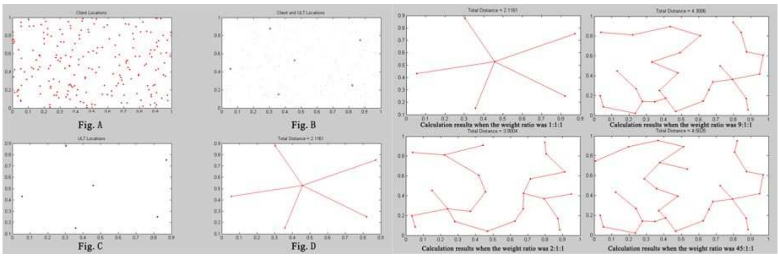

Fig. 1. Calculation results when the weight ratio was 1:1:1

Weight ratio	Terminal quantity	Objective function value	Channel length (unit of length)	Computation time (s)	Terminal average service distance (length unit)
1:1:1	6	0.0357	2.1161	1.2813	0.1605
2:1:1	23	-0.0468	3.9004	1.3438	0.0689
45:1:1	31	-4.1478	4.5025	1.2656	0.0528
6:3:3	23	-0.2660	3.9004	1.2969	0.0689

When max $\left\{\frac{1}{n_j}\sum_{j=1}^{n_j}\left\{Dtc_{jl}\left|j\in N_j\right.\right\}\left|l=1,2,\cdots,n\right.\right\}\leq 0.25$, the weight changed and the number of underground logistics terminal, the target function value and other indicators were analyzed in detail, as shown in table 2. The weight of customer service level played a leading role in the layout of the entire underground logistics network. The weight of customer service and the other 2 weights was similar to (1:1:1) or lower than the other 2 weight, the number of underground logistics terminal customer accounts for 3% of the total, the average underground logistics terminal served 33.3 customers, the average distance between customers and underground logistics terminal 0.1605 (length unit); when the customer service level of weight increased 2:1:1, the number of underground logistics terminal customer accounted for 11.5% of the total, the average underground logistics terminal served 8.7 customers, the average distance between customers and underground logistics terminal 0.0689 (unit of length); when the customer service level of weight increased to 45:1:1 or more, the number of underground logistics terminal customer accounted for 15.5% of the total, average each underground logistics terminal served 6.5 customers, the average distance between customers and underground logistics terminal 0.0528 (unit of length). The layout of the remaining weight ratio was the same as that of the first 3 rows of Table 2(as shown in Figure 1).

5. Conclusions

The monoline channel and sibling terminal layout model of urban underground logistics was established. The method and steps of solving model, and the judgment criterion and test standard of the solution process were given. Finally, the large scale underground logistics network layout example showed that the model could reflect the layout planning objectives and requirements, the algorithm could accurately and quickly solve the model. It was found the level of customer service would impact on the entire layout, which would become the important factor of underground logistics system construction. In a word, the method could effectively solve the problem of the terminal tunnel layout of underground logistics, and provide a systematic, scientific and visual decision-making basis for planning and building the underground logistics system.

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