International Journal of Business and Management
www.ccsenet.org/journal.html
Vol. 4, No. 11
November 2009

Research on an Optimization Model for Logistics Nodes System Layout and Its Solution Algorithm

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Abstract

Based on the logistics nodes system consisting of first-degree logistics node (logistics park) secondary logistics nodes (including logistics center and distribution center), a dynamic logistics nodes location model of multi-period , multi-type cargo flow and multiple logistics nodes is given. The optimization model considers the factors including fixed cost for logistics opening, handling cost and economic of scale of different type logistics nodes. An effective algorithm based on the improved minimum cost-maximal flow algorithm and genetic algorithm is presented according to the characteristic of optimization problem. Finally, a numerical example is provided to validate the proposed model and solution algorithm. The findings indicate that the model proposed in this paper is a useful tool for the investigation of the Multi-period and Multiple Logistics Node Dynamic Location Problem.

Keywords: Logistics nodes, System layout, Optimization model, Heuristic rules, Hybrid genetic algorithm

1. Introduction

The logistics network design of a city is very important to reduce the social distribution costs and improve the efficiency of distribution. The literature on the city logistics network design problem is extensive with a wide variety of solution methods. Ballou (1968) was the first to address the dynamic location problem and suggested a heuristic algorithm for its solution. Geoffrion and Graves (1974) provided a solution procedure based on Bender's decomposition and applied it to a real situation for a major food company. Denis (1976) investigated the multi-commodity and multi-period e facility location problem, and gave the heuristics algorithm based on dynamic programming. Alexander (1991) studied the multi-period and multi-stages location problem, and solves the model by the Lagrangian heuristics combined with dynamic programming. John (1997) proposed a dynamic location model with uncertain quantity facilities by applying the heuristics based on decision criteria: the minimization of expected opportunity loss and the minimization of maximum regret. Nozick (2001) presents a combined location model considering facility costs, inventory costs, transportation costs, and customer's responsiveness. A comprehensive review on the facility location model can be found in Andreas Klose et al. (2005).

In this paper, we present an optimization model to solve the capacitated, multi-commodity, multi-period, multi-class logistics node location problem. And an effective algorithm is given which is based on hybrid algorithm and heuristic rules.

The rest of this paper is organized as follows. In Section 2 we present an optimal mathematical model of the capacitated, multi-stage, multi-commodity dynamic logistics nodes location problem. Section 3 provides the development of the algorithm for solving this problem. The fourth section presents an illustrated application, while the last section presents conclusions and suggestions for further research.

2. Model formulation

In this paper, we consider a city long-term logistics nodes system planning according to its logistics need changes in the future 2 years. The logistics nodes systems planning consists of three stages, taking from 1 to 5 as stage 1, from 5 to 10 as stage 2, and from 10 to 20 as stage 3. The logistics nodes are made up of the first class logistics nodes and the second class logistics nodes. The first class logistics nodes have the logistics hub function, such as Logistics Park. While the second class logistics nodes have the distribution function, such as Logistics Center and Distribution Centers. We denote the first class logistics nodes as LN (I), the second logistics nodes as LN (II). The planning aim is to enhance distribution efficiency and cut down the society logistics cost by optimizing the layout logistics nodes step by step.

The assumptions to the model are as follows.

(1) There are n1 candidate locations of LN(I), n2 candidate locations of LN(II) and m customer demand spots, where LN(I), LN(II) represents the first class logistics nodes.

(2) The candidate logistics nodes are satisfied on traffic conditions and others necessary location conditions.

(3) The design parameters and relative construction cost of each potential logistics nodes are known in advance.

(4) The transportation costs among LN (I) nodes, LN (II) nodes and customers are given.

(5) The demand of customer zones is obtained in advance.

Inputs and Sets

I : set of the candidate locations of first class logistics nodes, indexed by i

J: set of the candidate locations of second class logistics nodes, indexed by j

N: set of customer locations, indexed by n

M: set of the commodities, indexed by m

T : set of the planning time, indexed by t

$F_k(t)$: the fixed cost of operating logistics nodes k in time t; $k \in I \cup J$

$C_{ij}^m(t)$: the unit shipment cost of commodity m from LN(I) i to LN(II) j in period t

$C_{jn}^m(t)$: the unit shipment cost of commodity m from LN(II) j to customer n in period t

$C_k^e(t)$: the expanding cost of logistics nodes k in time t; $k \in I \cup J$

$U1_i(t)$: the initialization design capacity of LN(I) i for commodity m in time t, $i \in I$

$U2_j(t)$: the initialization design capacity of LN(II) j in time t, $j \in J$

$U_i^{\max}(t)$: the maximal capacity of LN(I) i by expanding in time t, $i \in I$

$U_j^{\max}(t)$: the maximal capacity of LN(II) j by expanding in time t, $j \in J$

$D_n^m(t)$: the demand of customer n for commodity m in time t,

$\varphi_i^1(t)$, $\varphi_j^2(t)$: the unit cost of process of LN(I) i and LN(II) j in time t respectively.

$\theta_i^1(t)$, $\theta_j^2(t)$:the relative agglomeration factors in LN(I) i and LN(II) j in time t respectively.

(generally speaking, $0 \le \theta_i^1(t) \le \theta_j^t(t) \le 1$, and the less the value of agglomeration factors, the more the benefit of scale economy)

$R_i^1(t)$, $R_j^2(t)$: the total shipment of LN(I) i and LN(II) j in time t respectively, $i \in I$, $j \in J$

a_i^t , b_j^t : the expanding cost of LN(I) i and LN(II) j in time t respectively, $i \in I$, $j \in J$

$A_k(t)$: the equal instalment system

$A_k(t) = F_k \dfrac{r(1+r)^{N_k^0}}{(1+r)^{N_k^0}-1} \quad \forall t \le n_k^0 \qquad A_k(t) = 0 \quad \forall t > n_k^0$ where, n_k^0 : the investment recovery period of logistics node k; r : the capital discount rate;

S_k^t : the salvage value of the closed logistics nodes k in time t $S_k^t = \sum_{\tau=1}^{N_k - t} A_k (1+r)^{-\tau}$

$Dec(f)$: sign function, if f>0, Dec(f)=1, otherwise Dec(f)=0;

Decision variables:

$X_{ij}^{m}(t)$: the quantity of commodity *m* shipped from LN(I) *i* to LN(II) *j* in time *t*

$X_{jn}^{m}(t)$: the quantity of commodity *m* shipped from LN(II) *j* to customer *n* in time *t*, $Y_k(t)$:the indicator variable for logistics node *k* building status (0=closed, 1=open)

$E_k(t)$: the indicator variable for logistics node *k* expanding status (0=closed, 1=open)

The capacitated, multi-stage, multi-commodity, dynamic logistics nodes location problem (CMDLNLP) can be formulated as follows:

$$Min \quad NPV(X,Y,E)=\sum_{t\in T}\{[TC(X,Y,t)+OC(X,Y,t)+AC(X,Y,t)]*(1+r)^{-(t-1)}\} \quad (1)$$

where

$$TC(X,Y)=\sum_{m\in M}(\sum_{i\in I}\sum_{j\in J}C_{ij}^{m}X_{ij}^{m}(t)+\sum_{j\in J}\sum_{n\in N}C_{jn}^{m}(t)(X_{jn}^{m}(t))$$

$$OC(X,Y)=\sum_{i\in I}\varphi_i^1(R_i^1(t))^{\theta_i^1(t)}+\sum_{j\in J}\varphi_j^2(t)R_j^2(t)^{\theta_j^2(t)}+\sum_{t\in T}\sum_{k\in I\cup J}A_k(t)Y_k(t)Dec(t-n_k^0)$$

$$AC(Y,K)=\sum_{i\in I}a_i^tK_i(t)+\sum_{j\in J}b_j^tK_j(t)-\sum_{k\in I\cup J}S_k^t((Y_k(t-1)-Y_k(t))$$

subject to

$$\sum_{m\in M}\sum_{j\in J}X_{ij}^{m}(t)\le U_i^{\max}(t) \qquad \forall i\in I,t\in T \quad (2)$$

$$\sum_{m\in M}\sum_{n\in N}X_{jn}^{m}(t)\le U_j^{\max}(t) \qquad \forall j\in J,t\in T \quad (3)$$

$$\sum_{i\in I}X_{ij}^{m}(t)=\sum_{n\in N}X_{jn}^{m}(t) \qquad \forall j\in J,m\in M,t\in T \quad (4)$$

$$\sum_{j\in J}X_{jn}^{m}(t)=D_n^m(t) \qquad \forall n\in N,m\in M,t\in T \quad (5)$$

$$\sum_{m\in M}\sum_{j\in J}X_{ij}^{m}(t)=R_i^1(t) \qquad \forall i\in I,t\in T \quad (6)$$

$$\sum_{m\in M}\sum_{n\in N}X_{jn}^{m}(t)=R_j^2(t) \qquad \forall j\in J,t\in T \quad (7)$$

$$E_i(t)=Dec(R_i^1(t)-U1_i(t)) \qquad \forall i\in I,t\in T \quad (8)$$

$$E_j(t)=Dec(R_j^2(t)-U2_j(t)) \qquad \forall j\in J,t\in T \quad (9)$$

$$X_{ij}^{m}(t)\ge 0 \qquad \forall i\in I,j\in J,m\in M,t\in T \quad (10)$$

$$X_{in}^{m}(t)\ge 0 \qquad \forall i\in I,n\in N,m\in M,t\in T \quad (11)$$

$$X_{jn}^{m}(t)\ge 0 \qquad \forall j\in J,n\in N,m\in M,t\in T \quad (12)$$

$$Y_k(t)=\{0,1\} \qquad \forall k\in I\cup J,t\in T \quad (13)$$

In the above formulation, the objective function involves three types of costs: transport costs, handle and fixed costs, and the transitional costs related to the dynamic nature of the problem. It aims to minimize the sum of the costs including: the costs of transport commodity from LN (I) to LN (II) and from LN (II) to customer; the fixed cost associated with locating and operating logistics nodes; the transitional costs of logistics nodes due to expanding and closing.

Constraint set (2) stipulates that all shipments from LN (I) to LN (II) must not exceed its capacity. The capacity restriction of LN (II) is ensured by constraint set (3). Constraint set (4) indicates a conservation of flow at each logistics node, while (5) requires that all customer demands must be met. Constraint sets (6), (7) indicate that the total shipment processed by LN (I) nodes and LN (II) nodes respectively. Constraint set (8), (9) imply the LN (I) nodes and LN (II) nodes to be expanded or not respectively. The non-negativity on each shipment is imposed by constraint sets (10)-(12). Constraint set (13) on $Y_k(t)$ restricts every logistics node to be either open or closed.

3. Solution algorithm

The above model is a nonlinear optimization model extended from the static location problem. Thus, to this optimization model, it is hard to obtain the optimization solution by classical optimization methods. An effective heuristic algorithm is given which is based on genetic algorithm and heuristic rules in the paper.

The proposed algorithm is segmented into two phases. In phase I, the optimal static solution for the first planning period is obtained by hybrid genetic algorithm. In phase II, based on the above optimal solution, the optimal solutions for the second and third planning period can be acquired by heuristic rules.

(1) the description of heuristic rule

In the following discussion, $K_o(t)$ and $K_C(t)$ stand for the set of logistics nodes that are open and closed in period t respectively. $Z(K_o(t))$ denotes the optimal objective function value for the static problem of DMLNLP in period t, with $K_o(t)$ being the set of open facilities in the optimal static solution.

Let $Z(\nabla_j^t)$, $Z(\perp_j^t)$ be the sum of transport costs and operator costs in the objective function value (i.e. the sum of TC and OC in the objective function) before the logistics node i expanding and after expanding in period t, respectively.

Let $DD_j(t)$, $DO_j(t)$ and $DE_j(t)$ be the change value of the sum of transport costs and operator costs in the objective function due to logistics node j opening ,closing and expanding in period t, respectively.

heuristic rules

(1) opening rule: if the savings in opening logistics node *j* at time *t* is more than additional investment with opening, it is rational to open logistics node *j*. It can be expressed as:

$$DD_j(t) = [Z(K_o(t)+j) - Z(K_0(t))] > F_j \quad \forall j \in K_C(t) \tag{14}$$

(2) closing rule: if the savings in closing logistics node j at time t is more than additional costs of transporting and operating with closing, it is rational to close logistics node j. It can be expressed as:

$$DO_j(t) = Z(K_o(t)) - Z(K_0(t) - j) < S_j^t \quad \forall j \in K_O(t) \tag{15}$$

(3) expanding rule: if the savings in expanding logistics node j at time t is more than extra costs with closing, it is rational to expand logistics node j. It can be expressed as:

$$DE_j(t) = Z(\perp_j^t) - Z(\nabla_j^t) > a_j^t \qquad \forall j \in K_0(t) \tag{16}$$

(2) solution algorithm

Step 1: sorting by the capacity of logistics nodes and calculating the upper bound of the number of logistics nodes needed.

Step 2: Constructing the virtual network based on the above logistics nodes needed.

Step 3: Applying the hybrid genetic algorithm based on revised ford-fakon algorithm to obtain the static optima solution under T=1(i.e.in the first period planning), and denoting its optimal objective value $Z_1(n_i^*, n_j^*)$,where n_i^*, n_j^* is the number of LN(I) nodes and LN(II) nodes needed opening respectively.

Step 4: loading the flow of the second planning period into the optimal network of the first planning period, if the capacity of network can be meet the flow demand completely, goto Setp8 ;otherwise goto Step 5.

Step 5: Estimating the logistics nodes closed to the customers without fully satisfied according the above expanding rule, and calculating the minimum costs of expanding for all unsatisfied customers, denoting the extra expanding cost $Z_2(E)$.

Step 6: Estimating the logistics nodes closed to the customers without fully satisfied according the above opening rule, and calculating the minimum costs of opening for all unsatisfied customers, denoting the extra opening cost $Z_2(O)$.

Step 7: Comparing $Z_2(E)$ with $Z_2(O)$, if $Z_2(E) < Z_2(O)$, it is reasonable to expand; otherwise, it should take the plan of opening. By this method, the optimal solution under T=2 (i.e.in the first period planning) can be obtained. Go to Step9.

Step 8: Calculating and sorting ascend the ratio of the using of all logistics nodes opening of the optimal solution under T=1, and closing the logistics nodes with less ratio of the using according to the above opening rule. By this method, the optimal solution in T=2 (i.e.in the first period planning) can be obtained. Go to Step9.

Step 9: Loading the flow of the second planning period into the optimal network of the first planning period, and by imitating the operations of Step4-Setp8, the optimal network of the third planning period can be obtained.

Step 10: Getting the finally optimal dynamic solution.

(3) **Transformation of virtual network**

Insert Figure 1 here

As Fig.1 shown, if there are m candidate nodes of LN(I), n nodes of LN(II) and p customer zones, a virtual network can be constructed by adding a original node s and destination node t.

Denoting $I = \{1,2,\cdots,m\}$, $J = \{1,2,\cdots,n\}$, $M = \{1,2,\cdots,p\}$

d_{ij} : the distance of node I and node j, where $i, j \in I \cup J \cup M$

cap_{ij} : the throughput limit of the arc ij (from node *i* to *j*)

In the above virtual network, there exist the following rules:

(1) $d_{si} = 0; cap_{si} = \infty; \forall i \in I$

(2) $d_{ij} = c_{ij}; cap_{si} = U_{ij}; \forall i \in I, j \in J$ where C_{ij} denotes the transport costs between node *i* and *j*, U_{ij} denotes the maximum of the design capacity of node *i* and *j*.

(3) $d_{jk} = c_{jk}; cap_{si} = U_{jk}; \forall j \in J, K \in M$ where C_{jk} denotes the transport costs between node j and *k*, U_{jk} denotes the maximum between the design capacity of node *j* and the demand of customer zone *k*.

(4) $d_{kt} = 0; cap_{kt} = \infty; \forall k \in M$

(4) the description of coding and genetic operator s

It is very important on how to represent the solution of the investigating problem as chromosome and to design genetic operator. In general, the binary code is a good alternative. The representation of chromosome is denoted as $[u_1, u_2, \cdots u_m \mid v_1, v_2, \cdots, v_n]$.

It indicates that the candidate LN(I) *i* will be opened if ui is equal to 1 and the candidate LN(I) *i* will be opened if v*j* is equal to 1.

Based on the revised fork-fankson algorithm, the whole network flow assignment can be obtained and the objective function value is used to calculate the fitness of the associated chromosome.

Crossover operator is applied to the method of partially matched crossover (PMC). In order to ensure the feasibility of the offspring chromosome, it is necessary to fulfill remedy strategy. Zhao (2001) has given a detail description on the remedy strategy. The inversion operator is adopted for mutation operator in this paper.

4. A Numerical example

Suppose a city logistics nodes system planning is made according to its intending 20 years logistics demand changes, consisting of 3 stages: stage1 is from the first year to fifth year, stage 2 is from the sixth year to tenth year, and stage 3 is from the eleventh year to the twentieth year.

There are 6 potential LN (I) nodes (**I**), 22 LN (II) nodes (**J**) and 40 customer demand zones. Other input data is shown in the table1-5.

Insert Table 1 here

Insert Table 2 here

Insert Table 3 here

Insert Figure 2 here

The figure2 shows the change curve of objective function in the evolvement of GA algorithm.

According to the heuristics rules, the optimal result of the second period (T=2) is shown in table 7, and the optimal result of the third period (T=3) is shown in table 8.

Insert Table 7 here

Insert Table 8 here

5. Conclusions

In this paper, a dynamic logistics nodes layout optimal model is proposed to investigate the distribution network design problem with multi-period , multi-commodity and multiple logistics nodes An effective algorithm based on the hybrid genetic algorithm and heuristic rules is presented according to the characteristic of optimization problem. Finally, a numerical example is provided to validate the proposed model and solution algorithm. The findings indicate the following rules:

(1) The ratio of the distribution cost and the sum of fixed cost and handling cost will take great influence on the optimal configuration of logistics nodes. The logistics nodes opening become more if the ratio increases.

(2) The relative relation between unit expanding cost and open cost takes great effective on dynamic optimal solution. The measure of expanding is adopted when the supply capacity is deficiency, when the unit expanding cost is less than unit open cost.

(3) The genetic operator Pm influences on optimal solution and the speed of convergence while the PC will takes mild effective. The ideal parameters of the hybrid GA is as follows:

popsize=30, Pc=0.8, Pm=0.2,gen=150

Acknowledgements

This research was supported by Philosophy and Social Science Foundation of Central South University. NO.CSU0833

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Table 1. The design parameter of potential LN(I)

No.	$F_k(t)$ (10,000 yuan)	$U1_i(t)$ (10,000t/year)	$\varphi_i^1(t)$ (yuan/t)	$U_i^{max}(t)$ (10,000t/year)	$C_k^e(t)$ (10,000 yuan)	S_k^t (10,000 yuan)	$A_k(t)$ (10,000 yuan)
1	40000	4000	0.9	500	8000	120000	6510
2	46000	4600	0.8	500	8000	138000	7486
3	44000	4400	0.85	500	8000	132000	7161
4	38000	3800	1.0	500	8000	114000	6184
5	46000	4600	0.8	500	8000	138000	7486
6	32000	3200	1.1	500	8000	96000	5208

Note: suppose the investment recovery period of LN(I) is 10 years

Table 2. The design parameter of potential LN(II)

No.	$F_k(t)$ (10,000 yuan)	investment recovery period (year)	$U2_j(t)$ (10,000t/year)	$\varphi_j(t)$ (yuan/t)	$U_j^{max}(t)$ (10,000t/year)	$C_k^e(t)$ (10,000 yuan)	S_k^t (10,000 yuan)	$A_k(t)$ (10,000 yuan)
1	8400	5	700	1.6	200	3500	3500	2216
2	8400	5	700	1.6	200	3500	3500	2216
3	4800	3	400	1.8	100	2000	2000	1930
4	6000	5	500	1.6	125	2500	2500	1583
5	6600	5	550	1.6	150	2750	2750	1741
6	6600	5	550	1.6	150	2750	2750	1741
7	4200	3	350	1.8	80	1750	1750	1689
8	7800	5	650	1.6	170	3250	3250	2058
9	4200	3	350	1.8	80	1750	1750	1689
10	4200	3	350	1.8	80	1750	1750	1689
11	6600	5	550	1.6	150	2750	2750	1741
12	4800	3	400	1.8	100	2000	2000	1930
13	7800	5	650	1.6	170	3250	3250	2058
14	7200	5	600	1.6	150	3000	3000	1899
15	4200	3	350	1.8	80	1750	1750	1689
16	6000	5	500	1.6	125	2500	2500	1583
17	4800	3	400	1.8	100	2000	2000	1930
18	5400	5	450	1.6	110	2250	2250	2171
19	4800	3	400	1.8	100	2000	2000	1425
20	4800	3	400	1.8	100	2000	2000	1930
21	4200	3	350	1.8	80	1750	1750	1689
22	7200	5	600	1.6	150	3000	3000	1899

Table 3. The demand of customer zones (10,000t/year)

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
T=1	264	240	256	248	208	264	272	216	170	190	150	140	130	110
T=2	314	290	306	298	258	314	322	266	200	220	180	170	160	140
T=3	414	390	406	398	358	414	422	366	270	290	250	240	230	210
No.	15	16	17	18	19	20	21	22	23	24	25	26	27	28
T=1	120	130	130	140	110	110	65	90	85	70	60	85	85	95
T=2	150	160	160	170	140	140	75	100	95	80	70	95	95	105
T=3	220	230	230	240	210	210	115	140	135	120	110	135	135	145
No.	29	30	31	32	33	34	35	36	37	38	39	40		
T=1	65	55	95	90	80	75	50	60	90	80	50	60		
T=2	75	65	105	100	90	85	60	70	100	90	60	70		
T=3	115	105	145	140	130	125	100	110	140	130	100	110		

Notes: T=1 represents the first planning period; from 1 to 5; T=2 represents the second planning period, from 6 to10; T=3 represents the third planning period, from 10 to 20.

Table 4. The unit transport cost from LN (I) to LN(II) (yuan/t)

Cij	1	2	3	4	5	6	Cij	1	2	3	4	5	6
1	7	12	17	4	3	6	**12**	11	8	9	17	9	5
2	16	12	10	13	14	7	**13**	12	7	8	7	5	11
3	14	14	3	15	15	4	**14**	11	6	5	11	8	16
4	3	16	12	14	8	12	**15**	12	12	3	14	4	6
5	8	5	5	10	13	11	**16**	7	3	7	6	14	16
6	12	16	6	15	17	7	**17**	9	15	14	5	17	5
7	13	11	15	10	12	6	**18**	8	14	10	4	13	9
8	8	15	15	5	5	11	**19**	4	11	8	14	9	3
9	9	12	4	6	11	3	**20**	14	9	13	13	9	5
10	9	14	3	6	6	11	**21**	14	14	9	6	6	16
11	6	6	14	8	13	10	**22**	16	8	7	11	12	7

Table 5. The unit transport cost from LN(II) to customer zones(yuan/t)

LN(II) No.	the transport cost from LN(II) to 1-40 customer zones ,respectively.
1	10, 7, 6, 2, 1, 10, 10, 7, 9, 4, 5, 9, 5, 10, 10, 3, 6, 6, 4, 4, 4, 8, 5, 4, 9, 1, 9, 9, 1, 7, 9, 2, 10, 9, 10, 8, 3, 3, 9, 3
2	9, 10, 1, 8, 9, 2, 6, 9, 7, 2, 3, 5, 3, 6, 9, 7, 3, 7, 6, 4, 10, 3, 5, 7, 2, 9, 3, 2, 2, 10, 8, 7, 3, 10, 6, 3, 1, 1, 4, 10
3	2, 9, 2, 10, 6, 4, 3, 6, 3, 6, 9, 7, 8, 8, 3, 3, 10, 5, 2, 10, 7, 10, 9, 3, 6, 6, 5, 10, 2, 3, 6, 1, 9, 4, 10, 4, 10, 7, 8, 10
4	10, 8, 7, 10, 4, 6, 8, 7, 7, 6, 9, 3, 6, 5, 5, 2, 7, 2, 7, 4, 4, 6, 6, 4, 3, 9, 3, 6, 4, 7, 2, 9, 7, 3, 2, 5, 7, 3, 10, 2
5	6, 1, 4, 7, 5, 10, 3, 10, 4, 5, 5, 1, 6, 10, 7, 4, 5, 3, 9, 9, 8, 6, 9, 2, 3, 6, 8, 5, 5, 5, 5, 5, 3, 10, 4, 1, 8, 8, 9, 8
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According to the above algorithm and given data, the simulation result is as follows.

Table 6. The optimization configure of logistics nodes in the first period (T=1)

Logistics nodes opening		Flow Assignment	Total flow
LN(I)	LP3	DC2(700), DC5(532), DC99(350), DC14(595)	2177
	LP4	DC1(606) , DC8(650) , DC11(550) , DC13(650) , DC18(450)	2906
LN(II)	DC1	C4(248) , C5(208) , C26(85) , C29(65)	606
	DC2	C3(256) , C6(34),C10(190) , C17(130),C37(90)	700
	DC5	C2(240),C12(140),C18(22),C24(70),C36(60)	532
	DC8	C15(116),C18(34),C22(90),C23(85),C25(60),C31(95) C32(90),C33(80)	650
	DC9	C1(264),C20(86)	350
	DC11	C8(5),C13(130),C16(130),C27(85),C28(95), C30(55),C35(50)	550
	DC13	C6(230),C8(211),C18(84),C21(65),C40(60)	650
	DC14	C9(170),C14(110),C19(110),C34(75),C38(80),C39(50)	595
	DC18	C7(272),C11(150),C15(4),C20(24)	450
Costs	(1) total cost every year=79751 ten thousand; where distribution cost=36502 ten thousand, fixed cost=32152 ten thousand, operator cost=11097 ten thousand (2)Total cost =332555.44 ten thousand in T=1		

Notes: (1) LP_i denotes the logistics node *i* belonging to the type of LN(I); DC_j denotes the logistics node *j* belonging to the type of LN(II); c_k denotes the customer zone k(2)the unit of flow is ten thousand ton/ per year.

Table 7. The optimization configure of logistics nodes in the second period (T=2)

Logistics nodes opening		Flow Assignment	Total flow
LN(I)	LP3	DC2(700), DC4(493),DC5(550), DC9(350), DC14(600)	2693
	LP4	DC1(700), DC8(650), DC11(550), DC13(650), DC18(450) DC21(350)	3350
LN(II)	DC1	C4(248), C5(258), C26(95), C29(49)	700
	DC2	C3(306), C10(220), C29(26), C38(75), C37(73)	700
	DC4	C16(196), C18(204), C35(100)	493
	DC5	C2(115), C12(205), C24(120), C36(110)	550
	DC8	C1(64), C12(35), C18(36), C23(135), C25(110) C32(140), C33(130)	650
	DC9	C1(210), C20(140)	350
	DC11	C7(52), C18(75), C13(160), C27(93), C28(105), C30(65)	600
	DC13	C6(314), C8(191), C21(75), C40(70)	650
	DC14	C9(200), C14(140), C19(100), C34(85), C38(15), C39(60)	600
	DC18	C7(270), C11(180)	450
	DC21	C15(150), C17(160), C19(40)	350
Costs	(1) total cost every year=75934 ten thousand; where distribution cost =46129 ten thousand, fixed cost=13344 ten thousand, operator cost=13401 ten thousand, the cost of logistics nodes changing=3060 ten thousand (2)Total cost=316634 ten thousand in T=2		
notes	The logistics node configure changes of the second period is to add the DC4 and DC21, comparing with that of the first period.		

Table 8. The optimization configure of logistics nodes in the third period (T=3)

Logistics nodes openning		Flow Assignment	Total flow
LN(I)	LP3	DC2(850), DC4(664), DC5(550)DC9(350), DC14(750)DC16(495), DC22(600)	4259
	LP4	DC1(688), DC8(650), DC6(550),DC11(550), DC13(639), DC18(450), DC21(330)	4207
LN(II)	DC1	C4(398), C5(6), C6(258), C26(95), C29(49)	688
	DC2	C3(406), C10(290), C17(4), C8(150)	850
	DC4	C8(70), C16(196), C18(204), C20(90), C27(10),C35(100)	664
	DC5	C2(115), C12(205), C24(120), C36(110)	550
	DC6	C2(275), C8(135), C37(140)	550
	DC7	C7(124),C17(226)	350
	DC8	C1(64), C12(35), C18(36),C23(135),C25(110) C32(140),C33(130)	650
	DC9	C1(350)	350
	DC11	C7(98),C13(202),C28(145),C30(105)	550
	DC13	C6(414),C21(115),C40(110)	639
	DC14	C9(270),C34(125), C38(130),C39(100),C27(125)	750
	DC16	C19(210),C22(140), C31(145)	495
	DC18	C7(200),C11(250)	450
	DC21	C14(210),C20(120)	330
	DC22	C5(352),C13(28),C15(220)	600
costs	(1) total cost every year=86002 ten thousand; where distribution cost =58214 ten thousand, fixed cost=6910 ten thousand, operator cost=16218 ten thousand, the cost of logistics nodes changing=4660 ten thousand, (2)Total cost=3,586,160,000.8 yuan ten thousand in T=3		
notes	The logistics node configure changes of the second period is to expand the capacity of the DC2, DC4, DC14; DC21, LP4; to add new nodes DC6, DC7, DC16, DC22.		

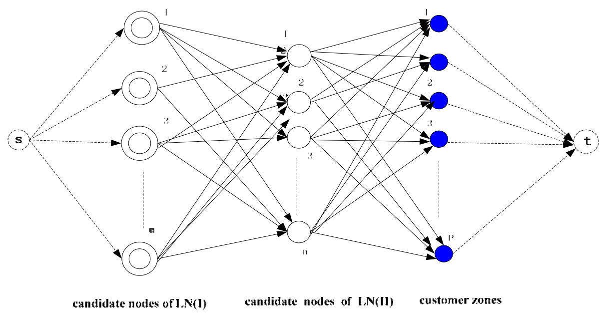

Figure 1. Virtual logistics network

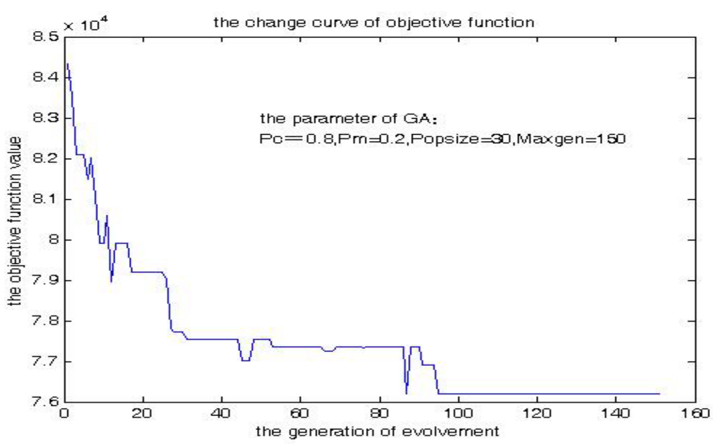

Figure 2. The change curve of objective function