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Multi-fuzzy two-echelon location routing problem with pick and delivery model and algorithm in B2C

Hong Li[1,*], Shujian Li[1]

Abstract. With the rapid development of B2C e-commerce, the logistics distribution system has a situation of high cost and poor service levels. In this paper, according to the characteristics of B2C, we proposed a multi-fuzzy two-echelon location routing problem with pick and delivery model. The model contains two fuzzy factors: the fuzzy customer behavior in the process of consumption and the fuzzy time of traffic in logistics distribution vehicle. In addition, model also consider the customer's time window constraint. The model we proposed can further optimize the logistics distribution system, and reduce the total cost of logistics system. For a variety of fuzziness and complexity, this paper designed the random fuzzy simulation algorithm to transform the fuzzy factors as the certainty factor, embedding tabu search of simulated annealing algorithm for problem solving. In the end, the experiment of algorithm and model design are verified.

Key words. Multi-fuzzy factors, Pickup and delivery, Two-echelon location routing problem, Simulated annealing algorithm, Random fuzzy simulation algorithm.

1. Introduction

With the rapid development of B2C e-commerce in China, there is phenomenon inconsistent with market development of online shopping in the B2C logistics distribution system, such as high logistics cost and poor service level and so on, which has attracted the attention of many researchers. On the one hand, for the purpose of reducing the delivery costs, it is necessary to comprehensively consider facility location and routing optimization in the distribution network so as to select the reasonable distribution service point, arrange delivery capacity and plan distribution routing, thus reducing the total costs of distribution network, that is, location routing problem (LRP). The judge of decision maker is jointly affected by a variety

[1]School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China

*. Corresponding author

of fuzzy factors in real life, and the influence of a variety of fuzzy factors increases the difficulty of the B2C e-commerce enterprise in the design of logistics distribution plan. The paper proposes 2E-LRP model with multiple fuzzy factors, introduces fuzzy demand and fuzzy running time in order to solve above problems, so as to select the site of new distribution facility node built by B2C e-commerce and plan and design integrated vehicle service routing on the basis of site selection. As the B2C e-commerce fails to obtain the information of the new customer in advance and to judge whether the existing information is changed or valid, the conditions of distribution function cannot be determined by typical characteristics. Therefore, the paper reflects a variety of uncertainties by giving a definite range of fuzzy changes with fuzzy processing method against multiple fuzzy factors. In view of solving the algorithm, the paper proposes random fuzzy simulation algorithm and simulated annealing algorithm embedded in tabu search to solve the 2E-LRP with multiple fuzzy factors. In the end, the model and algorithm shall be checked by experimental instance.

2. Mathematical model

2E-LRP is defined as follows: a secondary distribution network is composed of several alternative distribution centers, several alternative transfer stations and demand points for known geographical locations. The goods start from the distribution center, pass through the transfer station and reach the demand point in the process of distribution, of which the distribution center, transfer station and corresponding distribution routing constitute the primary distribution network, and transfer station, demand point and corresponding distribution routing constitute secondary distribution network, as shown in Fig.1. Under the condition of knowing the capacity of the logistics facilities at all levels, the distribution vehicle capacity at all levels and the location of the demand point, the quantity and location as well as vehicle routing are required to be determined by 2E-LRP, thus minimizing the total logistics cost of the network. The total costs of logistics network include fixed cost of logistics facility node at all levels, fixed cost and driving costs of vehicles at all levels.

The following assumptions for 2E-LRP model with multiple fuzzy factors are carried out in this paper:

(1) The quantity, location and fixed cost of candidate distribution center, transfer station and customer point as well as fixed cost of distribution vehicles at all levels are known.

(2) The logistics facilities capacity and distribution vehicle capacity at all levels are known.

(3) The distance of each node is calculated by Euclidean distance and the distribution cost of unit length of distribution vehicles at all levels is known.

(4) Each customer point can be served by one vehicle and the distribution vehicles at all levels start from the node of the logistics facilities and return to the same logistics facilities node.

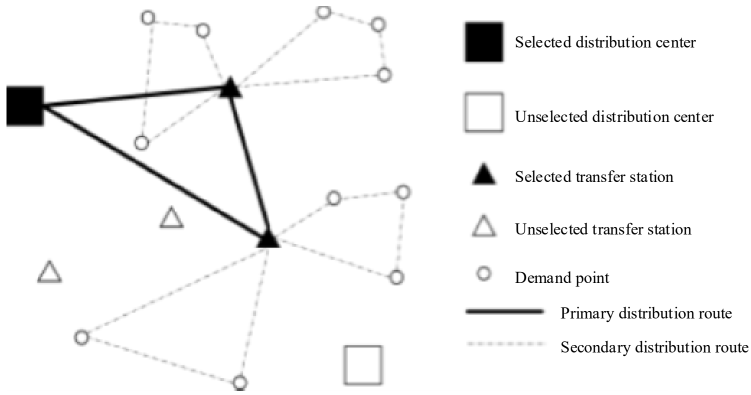


Fig. 1. Example of 2E-LRP network

3. Solving algorithm

It is difficult to solve the optimal solution through accurate algorithm within the acceptable time limits as LRP2 problem belongs to NP-hard problem, so some heuristic algorithms have gradually become the research hotspots of scholars at home and abroad. The paper designs the random fuzzy simulation algorithm and simulated annealing algorithm embedded in tabu search (SA-TS) to solve the 2E-LRP with multiple fuzzy factors. Random fuzzy simulation algorithm shall be used to carry out deterministic processing for customer fuzzy distribution, return quantity demand and fuzzy vehicle traveling time and convert fuzzy problems to the identified problems. With good convergence effect and insensitivity to initial parameter settings and other advantages, the simulated annealing algorithm has been applied to the research on LRP problem repeatedly. The optimization solution shall be implemented on the primary distribution network by tabu search that is able to quickly and efficiently solve the optimal solution or satisfactory solution of the primary distribution network due to its small relative scale. SA-TS adopts a bottom-up solution process, which first construct the neighborhood solution of secondary distribution network and then solve the primary distribution network solution by virtue of tabu search based on this in the process of iteration. The costs under M different customer delivery and return quantity demand shall be calculated repeatedly in accordance with fuzzy customer point scale while calculating the objective function value and its mean value shall be regarded as the objective function value of current solution.

3.1. Algorithm steps

In this algorithm, the random fuzzy simulation algorithm shall be first used to convert the fuzzy problems to identified problems and then generate initialization parameter and initial solution. The neighborhood solution of secondary distribution network is generated by neighborhood construction method during the process of iteration, then the primary distribution network solution is solved by tabu search algorithm in accordance with the neighborhood solution and the objective function value of the whole neighborhood solution is calculated in the end. The acceptance is executed and the optimal solution is updated in accordance with Monte Carlo acceptance criteria based on current solution and objective function value of neighborhood solution. Finally, update the temperature until meeting the algorithm termination condition, and return to the optimal solution.

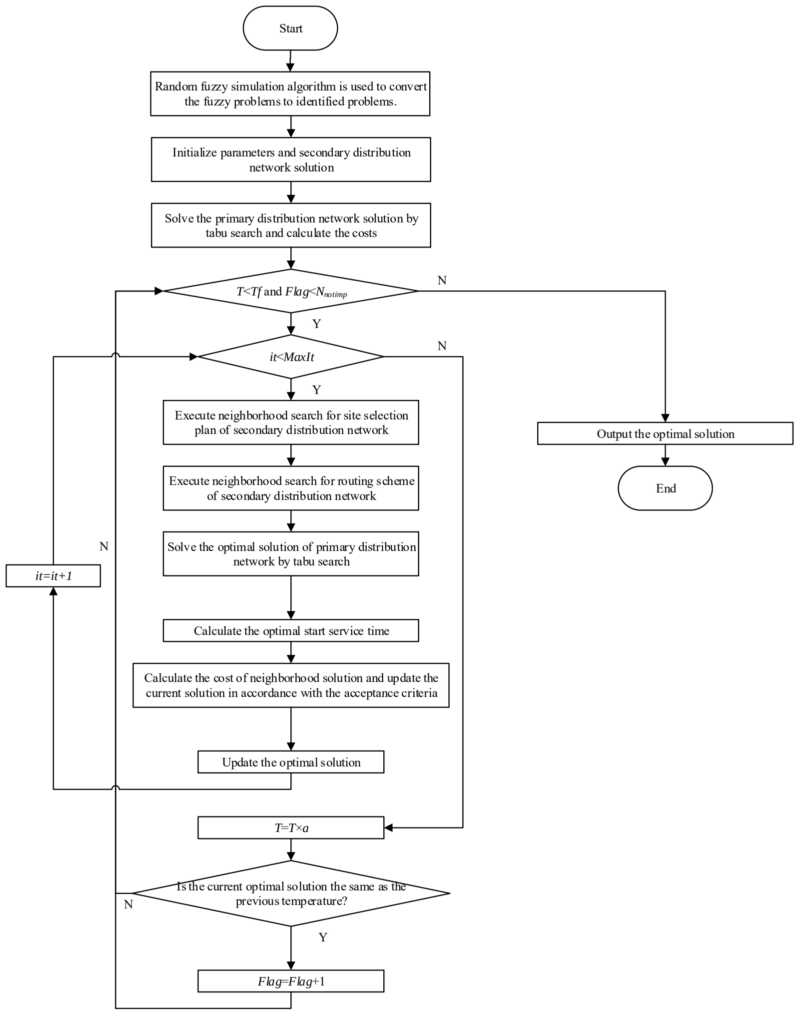


Fig. 2. Algorithm flow chart

The concrete steps of the algorithm are as follows and the algorithm process is shown in Fig.2.

Step 1: The customer fuzzy distribution, return quantity demand and vehicle fuzzy traveling time problems are processed by random fuzzy simulation algorithm, thus converting the fuzzy problems into identified problems.

Step 2: Initialize the parameters of the algorithm, including: initial temperature $T = T0$, the final temperature Tf, coefficient of temperature drop α, internal circulation times $MaxIt$, algebra not updated $Flag = 0$, $it = 0$ and the maximum algebra not updated N_{notimp}, and generate initial solution at random.

Step 4: If $it < MaxIt$, carry out Step 5; otherwise, given $it = 0$, execute Step 8.

Step 5: Construct neighborhood solution of secondary distribution network. Carry out neighborhood search for the site selection and routing of solved secondary distribution network respectively, and generate secondary distribution network solution of neighborhood solution $Xnew$. Calculate the total amount of distribution and return at customer point of each transfer station, as distribution and return quantity of the transfer station in accordance with the transfer station selected in the $Xnew$ secondary distribution network solution, and generate the primary distribution network solution of $Xnew$ at random.

Step 6: Solve the primary distribution network solution by tabu search. Carry out tabu search for the initial solution of primary distribution network of $Xnew$ and generate the optimal solution of primary distribution network of neighborhood solution $Xnew$.

Calculate the optimal start service time and total logistics cost $Xnew\_Cost$ of neighborhood solution $Xnew$.

Step 8: Update X according to the Monte Carlo acceptance criteria based on current solution X and neighborhood solution $Xnew$.

Step 9: Update the optimal solution. Update the optimal solution in accordance with the cost relationship between neighborhood solution Xnew and the optimal solution. If the optimal solution is updated, then given $Flag = 0$; otherwise, $Flag = Flag + 1$ and $it = it + 1$, then return to Step 3.

Step 10: $T = T \times \alpha$. If the optimal solution of the current temperature is the same as the previous one, then $Flag = Flag + 1$.

Step 11: If $T < Tf$ or $Flag = N\_\text{notimp}$, then end the algorithm and output the optimal solution; otherwise, return to Step 3.

3.2. Simulated annealing algorithm embedded in tabu search (SA-TS)

(1) Coding

This model contains two levels distribution networks. The solution is solved by the same real number coding because the solution of two levels distribution network is similar. Taking secondary distribution network as an example, the coding includes c customer point (s) numbered as $\{1,2,\cdots,c\}$, s alternative transfer station(s) numbered as $\{c+1,c+2,\cdots,c+s\}$ as well as several 0, representing the routing segmentation. The coding schematic diagram of secondary distribution network of 10 demand points and 5 alternative transfer stations is shown in the Fig.3, where 11 and 12 represent that the transfer station 1 and 2 are chosen to use, and unknown 13, 14 and 15 represent that transfer station 3, 4 and 5 are not chosen to use; 0 represents the routing segmentation symbol, the node in front of 0 is the end demand point of former routing and the node behind 0 represents the start demand point of the next routing. The coding of secondary distribution network as shown in Fig.3 can be converted into 3 paths:

1:11 -> 1 ->2 ->3 ->11 Path 1: 11 -> 1 ->2 ->3 ->11

2:11 -> 4 -> 5 -> 6 -> 11 Path 2: 11 -> 4 -> 5 -> 6 -> 11

3:12 -> 7 -> 8 -> 9 -> 10 -> 12 Path 3: 12 -> 7 -> 8 -> 9 -> 10 -> 12

11	1	2	3	0	4	5	6	12	7	8	9	10

Fig. 3. Example of coding with 10 customers and 5 satellites

(2) Initialization

The algorithm adopts the bottom-up solution process to initialize the secondary and primary distribution network respectively. On account of structural similarity of two levels distribution network, the initial solution is generated by the same greedy random initialization method in this paper. Taking the secondary distribution network as an example, the concrete steps of greedy random initialization are as follows:

Step 1: Distribute the customer points to any unused transfer station according to random order until the total demand or total return quantity demand of distributed customer point exceeds the capacity limitation of such transfer station, then judge whether there are remaining undistributed customers. If any, execute Step 2; otherwise, execute Step 3.

Step 2: Open a remaining unselected transfer station at random and return to Step 1.

Step 3: Optimize the greedy path of each transfer station. Taking the node of transfer station as the initial node, calculate the distance between the previous node to the nearest customer point as the next node, until all customers distributed to such transfer station are rearranged.

Step 4: Create a new path if partial paths exceed the dynamic capacity limitation of vehicle in accordance with the above paths and vehicle capacity limitation of secondary distribution network. The start nodes are the nodes of current transfer station.

(3) Neighborhood construction

Because the problem contains the two levels distribution network with similarity, the same neighborhood construction method shall be used in the process of solving and an example of secondary distribution networks is given as follows. The neighborhood construction process of secondary distribution network contains two parts: status updates of transfer station and route update.

1) Status updates of transfer station

The status of transfer station can be updated by closing, opening and exchanging the transfer station. The status of transfer station is not allowed to be updated again in a period after executing any method to update the status of transfer station because the status updates of transfer station will change the solution greatly, so only the routing can be updated to ensure that the optimal routing scheme can be found under the open state of the current transfer station. The status of transfer station can be updated as follows:

Step 1: Set up the parameters for status updates of transfer station such as g, $gmax$ and P_S when initializing the algorithm, and given $g = 0$.

Step 2: If $g > gmax$ and random number $Rand < P_S$, then execute Step 3; otherwise, $g = g + 1$, end.

Step 3: Select one to update the status of transfer station from three methods at random, and given $g = 0$.

2) Route update

The routing can be updated by 2-opt*, exchange and insert. Select one route update method at random when the neighborhood of secondary distribution network is constructed.

2-opt*: two nodes are selected as 2-opt* start and stop nodes in the remaining nodes from the first node except the coding at random in the decoding of secondary distribution network, and the sequence of each node in the start and stop node shall be inverted.

Exchange: two nodes are selected as exchange node in the remaining nodes from the first node except the coding at random, and the location of two nodes shall be exchanged.

Insert: two nodes are selected as insert node in the remaining nodes from the first node except the coding at random and the first selected insert node shall be inserted behind the second selected insert node.

Step 1: Initialize tabu search algorithm parameters, maximum execution algebra ($MaxIt$), candidate solution set length (CL), tabu list length (L), maximum algebra not updated (N_{notimp}), algebra not updated of optimal solution (Flag) and current algebra ($it = 0$), and then generate initial solution.

Step 2: Execute neighborhood search and generate candidate solution set.

Step 3: Update the current solution in accordance with the aspiration criterion and tabu criterion.

Step 4: Update the optimal solution. If the optimal solution is changed, given $Flag = 0$; otherwise, $Flag = Flag + 1$.

Step 5: If $it = MaxIt$ or $Flag = N_{\text{notimp}}$, end the algorithm and return to the current optimal solution; otherwise, back to Step 2.

(4) Optimal start service time

Influenced by new generated neighborhood solution, the start service time of each customer is the vehicle arrival time, that is, the service time can be started at the earliest. However, sometimes the arrival time of the vehicle may be earlier than the upper limit of the earliest start service time window required by the customer. At this point, the vehicle can be properly waited to improve the customer satisfaction of the current customer point. The relationship between waiting time and customer satisfaction is shown in Fig.5.

4. Experimental results and analysis

4.1. Algorithm validity check

(1) Algorithm parameters

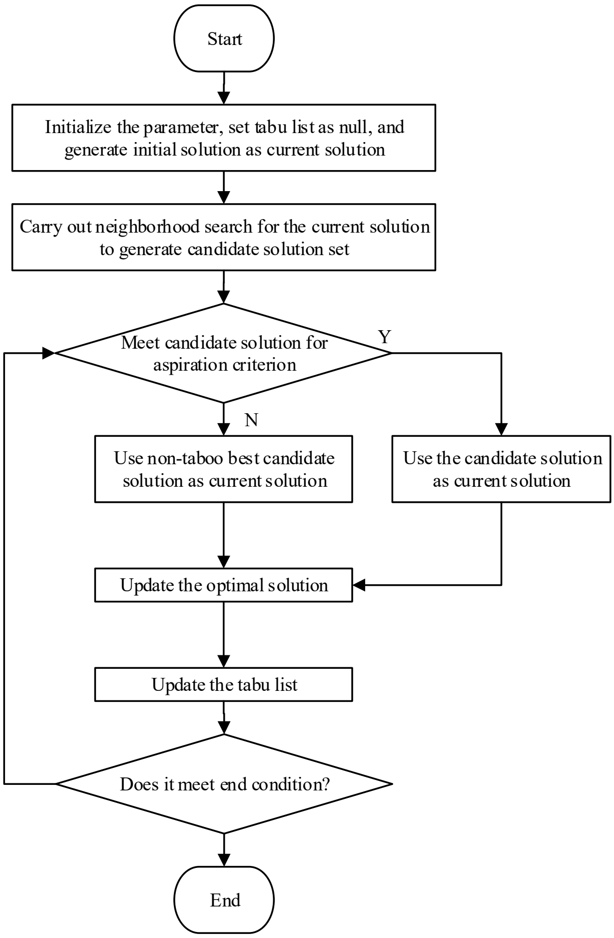


Fig. 4

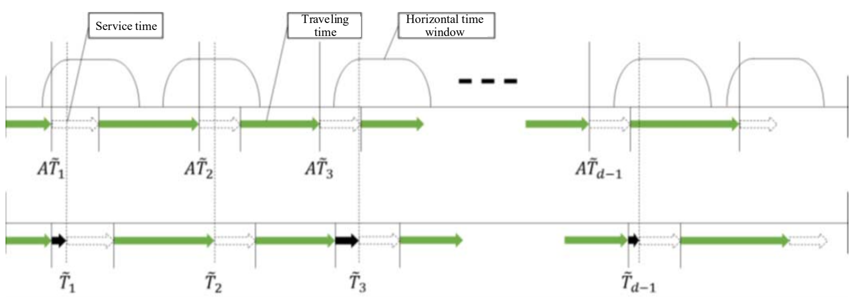


Fig. 5. Relationship between waiting time and customer satisfaction

The parameters of the simulated annealing include: initial temperature (T0), final temperature (Tf), coefficient of temperature drop (α), internal circulation times (MaxIt), and maximum algebra not updated (N_{notimp}). The parameters of tabu search include: maximum iterative algebra (TSMaxIt), maximum algebra not updated ($\mathrm{TSN_{notimp}}$), maximum number of candidate solution set (MaxCandList) and length of tabu list (L).

Table 1. Parameter values of SA

Parameters / Algorithm	$T0$	Tf	α	$MaxIt$	N_{notimp}
SA	50000	0.1	0.96	500	50

Table 2. Parameter values of TS

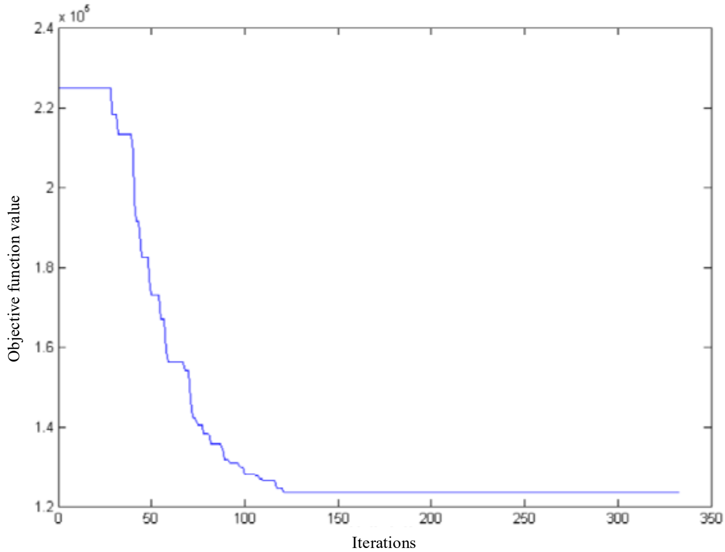
Parameters / Algorithm	$TSMaxIt$	TSN_{notimp}	$MaxCandList$	L
TS	5	3	10	2

(2) Comparative analysis of experimental results

The validity of SA-TS algorithm is verified by instances set Nguyen and compared with the GRASP algorithm in literature GRASP WITH LEARNING PROCESS FOR A TWO-ECHELON LOCATION ROUTING PROBLEM and the MS-ILS algorithm in literature A multi-start iterated local search with tabu list and path relinking for the two-echelon location-routing problem, of which the specific results are shown in Table 3. The paper only provides solution results of instance 50-5-MN and convergence curve of objective function value for more experimental results, as shown in Fig.6 and Fig.7.

Table 3. Results for 2E-LRP instances set nguyen

Instances	BKS*	GRASP	Gap	MS-ILS	Gap	SA-TS	Gap
25-5N	**80,370**	81,152	0.97%	**80,370**	0.00%	**80,370**	0.00%
25-5Nb	**64,562**	64,572	0.02%	**64,562**	0.00%	**64,562**	0.00%
25-5MN	**78,947**	80,412	1.86%	79593	0.82%	**78,947**	0.00%
25-5MNb	**64,438**	**64,438**	0.00%	**64,438**	0.00%	**64,438**	0.00%
50-5N	**137,815**	145,942	5.90%	138,126	0.23%	138,646	0.60%
50-5Nb	**110,094**	113,234	2.85%	111,290	1.09%	111,062	0.88%
50-5MN	**123,484**	126,313	2.29%	**123,484**	0.00%	**123,484**	0.00%
50-5MNb	**105,401**	106,033	0.60%	**105,401**	0.00%	105,846	0.42%
50-10N	**115,725**	116,709	0.85%	116,132	0.35%	116,132	0.35%
50-10Nb	**87,315**	90,559	3.72%	**87,315**	0.00%	**87,315**	0.00%
50-10MN	**135,519**	137,321	1.33%	136,123	0.45%	136,337	0.60%
50-10MNb	**110,613**	110,703	0.08%	**110,613**	0.00%	**110,613**	0.00%



Note: BKS represents the present international known optimal solution.

Fig. 6. Example of solution with instance of 50-5MN

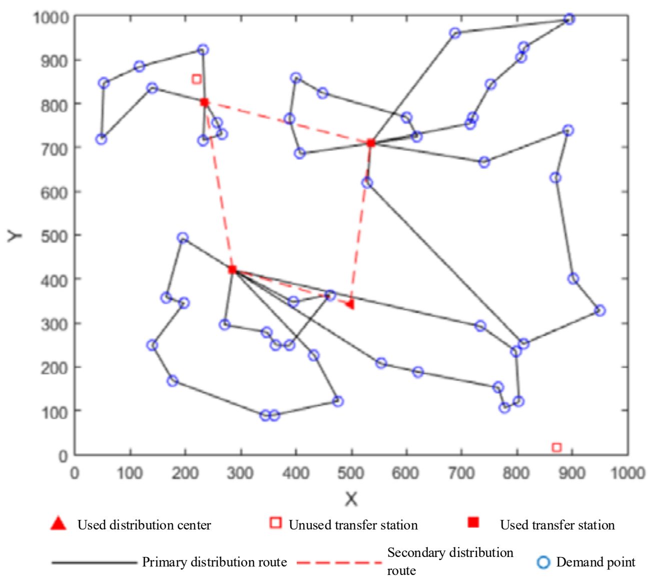


Fig. 7. Example of convergence trend graph with instance of 50-5MN

The experimental results show that the solving effect of SA-TS is the best when solving the scale problems of 25 customer points and the optimal solution can be found. The optimal solution cannot be found in some instances when solving the scale problem of 50 customer points, with less error. Compared with the GRASP algorithm, the solving effect of SA-TS is better. The optimal results are obtained in all test instances, with less error with the optimal solution. Compared to MS-ILS algorithm, the better results are obtained through such algorithm when solving the scale problem of 25 customer points, but the solving effect is similar when solving the scale problem of 50 customer points, with comparability.

4.2. Model validity test

The paper adds the related data as experimental instance data in the instance 25-5N of instance set Nguyen to verify the validity of fuzzy 2E-LRP mode proposed in this paper and to solve through the algorithm proposed in this paper.

(1) Return amount: the paper adopts the return amount generating method proposed by Angelelli and Mansini in literature [9]. The return amount is generated in accordance with the customer ID one by one, and the return amount p_i of the ith customer is as follows:

$$p_i = \begin{cases} (1+\alpha)\, d_i, & ii \text{ means odd number} \\ (1-\alpha)\, d_i, & ii \text{ means odd number} \end{cases}$$

Where, d_i represents the delivery amount of the ith customer and α is the random number between $[0.2, 0.8]$.

(2) Fuzzy distribution and return demand: trigonometric fuzzy number $\widetilde{d_i} = (d_{1,i}, d_{2,i}, d_{3,i})$ and $\widetilde{p_i} = (p_{1,i}, p_{2,i}, p_{3,i})$ of fuzzy distribution and return demand is generated in accordance with customer ID one by one.

$$\begin{array}{lll} d_{1,i} = (1-\alpha)\, d_i & d_{2,i} = d_i & d_{3,i} = (1+\alpha)\, d_i \\ p_{1,i} = (1-\alpha)\, p_i & p_{2,i} = p_i & p_{3,i} = (1+\alpha)\, p_i \end{array}$$

Fuzzy demand $\theta_d = 0.8$ and preference degree of fuzzy return amount $\theta_p = 0.8$.

(3) Fuzzy vehicle traveling time: the periodic road congestion parameters include: cycle time of congestion: $J_c = 50$, congestion cycle interval: $J_g = 50$, maximum cycle congestion coefficient: $J_{max} = 1$ and minimum cycle congestion coefficient: $J_{min} = 0.5$. The cyclical traffic congestion coefficient is reduced to the minimum value gradually from the maximum value within the congestion cycle, and then increased to the maximum value gradually and evenly. The cyclical traffic congestion coefficient is the maximum in the period of congestion cycle interval. Sudden road congestion coefficient is $R = \alpha^{1-J} - \beta$, where J represents the cycle congestion coefficient, α means the random number between $[0.5, 1]$ and β refers to the random number between $[0, 0.1]$.

(4) Penalty parameters: Unit penalty cost exceeding the capacity limit of transfer station: $OS = 100$; unit penalty cost exceeding the capacity limit of primary distribution vehicle: $OV = 40$; unit penalty cost exceeding the capacity limit of secondary distribution vehicle: $OK = 25$; unit penalty cost beyond the user's time window: $OT = 5$.

(5) Other parameters: vehicle running speed: 10; unit delivery service time: 1;

unit return service time: 1

Where, the geographic details of transfer station node and primary fixed cost information of capacity constraint are shown in Table 4, and the geographic details of customer point and information about soft time window are shown in Table 5.

Table 4. Transfer station information

Transfer station	X-coordinate	Y-coordinate	Capacity constraint	Fixed cost
1	600.656	503.332	332	5527
2	469.966	356.072	359	6894
3	468.705	627.231	331	4405
4	294.486	905.849	317	5570
5	652.129	723.145	365	3650

Table 5. Customer point information

Customer point	X-coordinate	Y-coordinate	Soft time window
1	918.283	709.536	[0,0,95,145]
2	577.06	134.427	[0,5,92,142]
3	575.991	271.526	[0,0,96,146]
4	579.94	694.336	[0,18,84,134]
5	660.582	356.212	[0,39,124,174]
6	236.192	174.807	[0,25,76,126]
7	484.405	572.263	[0,0,96,146]
8	600.786	740.53	[0,0,71,121]
9	892.965	592.959	[0,43,121,171]
10	287.499	391.33	[0,13,108,158]
11	437.226	699.173	[0,0,84,134]
12	499.022	721.307	[0,0,90,140]
13	279.812	807.543	[0,44,144,194]
14	328.354	457.081	[0,17,100,150]
15	365.208	344.893	[0,0,50,100]
16	737.698	785.66	[0,43,109,159]
17	357.351	501.733	[0,27,113,163]
18	438.39	414.691	[0,29,120,170]
19	969.968	572.002	[0,0,65,115]
20	631.052	133.572	[0,0,82,132]
21	423.349	740.151	[0,8,64,114]
22	873.183	145.156	[0,45,105,155]
23	502.492	407.532	[0,0,86,136]
24	377.464	254.122	[0,0,69,119]
25	533.624	291.449	[0,0,92,142]

The parameter setting of SA-TS algorithm is the same as the LRP-2E problem solving above-mentioned. The paper provides experimental result at a time for too much experimental data, as shown in Table 3. The solution result of instance 25-5N after expansion is shown in Fig.6.

The Table 3 shows that the SA-TS algorithm can effectively solve the expanded instance and optimize it through MATLAB software to obtain the approximate optimal solution in the end. The total cost of the optimization scheme is 90224.84 and No. 26 and 27 transfer stations are selected. 1 primary distribution vehicle and 6 secondary distribution vehicles are used, of which the routing is shown in Table 6. The result satisfies the minimum total cost principle of logistics distribution system in the whole process of logistics distribution, and the reasonable logistics network planning is carried out to make the resource distribute reasonably, showing that feasibility and practicability of the model.

Table 6. Operation result

Total cost	90224.84
Site selection of transfer station	No. 26 and No.27 transfer station
Number of used primary vehicles	1
Number of used secondary vehicles	6
Primary distribution route	0->26->27->0
1 Secondary distribution route 1	27->23->3->25->27
2 Secondary distribution route 2	27->14->17->11->21->13->18->27
3 Secondary distribution route 3	27->5->22->20->2->27
4 Secondary distribution route 4	27->15->10->6->24->27
5 Secondary distribution route 5	26->4->8->12->7->26
6 Secondary distribution route 6	26->16->1->19->9->26

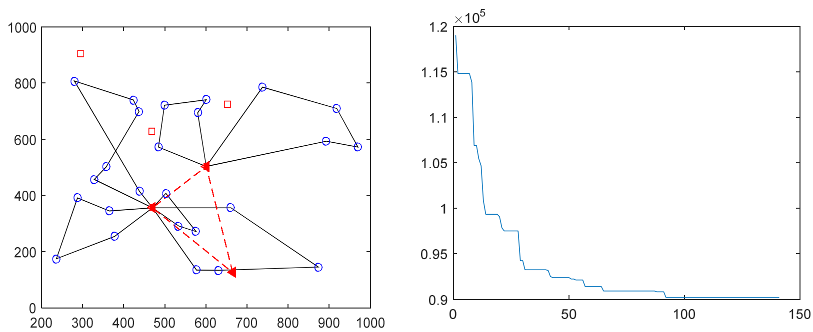


Fig. 8

The experiment shows that the fuzzy 2E-LRP model proposed in this paper is right and the random simulation algorithm and SA-TS algorithm proposed in this paper are reasonable and effective for solving the above problem model, which is a good method to solve this kinds of complex problem.

5. Conclusion

Based on characteristics of B2C distribution network, the paper establishes multi-fuzzy 2E-LRP model for optimization. Targeted at minimum total cost of logistics distribution for solving, the model integrates site selection of secondary distribution network node and distribution vehicle routing planning, which reduces the total cost of logistics operation in general and considers the fuzzy customer demand, fuzzy vehicle traveling time and soft time window constraint. Combined with the B2C e - commerce return problem, the model comprehensively considers the touring access characteristics of the distribution vehicles, forward and reverse logistics, and introduces the vehicle dynamic load constraint to ensure the effectiveness of forward and reverse logistics operation. The random fuzzy simulation algorithm and simulated annealing algorithm embedded tabu search proposed in this paper are reasonable and effective. The algorithm can find the international optimal solution in standard example of solving 2E-LRP with multi-fuzzy factors, which proves the effectiveness and generality of the algorithm, and can provide a reasonable and effective approximate optimal solution of 2E-LRP with multi-fuzzy factors. The 2E-LRP model with multi-fuzzy factors and solving algorithm proposed in this paper can provide effective decision-making support for the decision-makers of B2C logistics distribution enterprises.

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