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Disruption Management for Vehicle Routing Problem Based on Consumer Value and Improved Tree-Seed Algorithm

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ABSTRACT With the development of logistics, a well-designed distribution plan plays an important role in the distribution process. In order to improve the economic benefit of enterprise and customer satisfaction, this paper introduces the consumer value into disruption management for vehicle routing problem (VRP). Based on the consumer value that computed through expert evaluation and cloud model, the cloud model was adopted to classify the target consumers into three levels. Then, a consumer value-based VRP disruption management was established, which measures the deviations from the perspectives of consumer, distribution centre and driver. After that, the tree-seed algorithm (TSA) was improved by the immune algorithm (IA) to solve the established model, and proved valid through simulation. The research findings shed new light on the routing of distribution vehicles in the event of disruptions.

INDEX TERMS Vehicle routing, consumer value, disruption management, improved tree-seed algorithm.

I. INTRODUCTION

Logistics distribution, an important aspect of modern life, can be improved in many ways. For instance, a well-designed distribution plan helps to minimize the inevitable disruptions in the distribution process. Besides, the logistic enterprise can make more profits and improve consumer satisfaction through proper judgment, classification and management of consumers. So it is significant to consider the consumer value into disruption management for vehicle routing problem.

In 1959, Dantzig and Ramser [1] proposed the vehicle routing problem (VRP) to find the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers. Since then, many scholars have attempted to solve the VRP, with the aim to improve logistics distribution. For example, Pillac *et al.* [2] put forward the concept of dynamic degree based on information quality and changes, and utilized the concept to solve the dynamic VRP. Tas *et al.* [3] studied the VRP with flexible time window, and solved the problem with a tabu search algorithm. Ma and Wang [4] examined the logistics distribution VRP with backhauls, set up a two-way vehicle scheduling model based on mileage and the number of consumers, and solved the model with the particle swarm optimization (PSO), coupling hill-climbing algorithm. Ma *et al.* [5] constructed a VRP model to minimize the distribution cost, which consists of the transport cost and the driver wage. Li *et al.* optimized the carbon emission and velocity of the VRP. Zhou *et al.* [6] designed an encoding method based on the intelligent water drops (IWD) algorithm, and applied it to solve the VRP with soft time window. Pan and Gan examines the carbon emission in the logistics distribution of ordinary cold chains, sets up a model to convert carbon emission into profit, and solves the model by ant colony optimization (ACO).

In the VRP, disruptions often cause delays to logistics distribution and must be well managed [7], [8]. Hu *et al.* reviewed the history of disruption management, summed up the relevant models and algorithms, and pointed out the areas for future research. Wang *et al.* [9] develops a disruption recovery strategy with time window. Hu *et al.* [10] and Yan *et al.* [11] measured the disruptions in logistics distribution against consumer satisfaction, distribution cost

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and route error, and established a lexical order multi-objective disruption management model. Ding *et al.* [12] measured disruptions in the light of prospect theory, designed a lexical order multi-objective disruption management model, and improved the ACO to solve the model. Ding *et al.* [13] laid down different strategies for different consumer groups. Wang *et al.* build several disruption models for vehicle scheduling, and evaluate the value of each consumer before assessing consumer satisfaction [13]–[15].

To sum up, most studies on VRP disruption management either neglect consumer value or evaluate the value using a single index. This paper judges the consumer value in an all-round way and considers consumer value into disruption management for vehicle routing problem, then uses the improved tree-seed algorithm to solve the problem. Firstly, consumer value is evaluated iteratively by experts and the cloud model. Then, the consumers were classified by the cloud model based on consumer values. Next, a multi-objective VRP disruption management model was established. Finally, the tree-seed algorithm (TSA) was improved with the immune algorithm (IA) to solve the model [16]–[22], optimize the VRP and minimize the disruptions in logistics distribution.

II. MODELLING

A. ASSUMPTIONS

In our research, the VRP is subjected to the following hypotheses:

(1) The original distribution plan is the optimal solution to the VRP.
(2) Each vehicle must leave from a distribution center to the target consumer, and return to the distribution center after completing the delivery.
(3) Each vehicle can serve multiple consumers, but each consumer can only be served by one vehicle.
(4) No vehicle should be overloaded.
(5) All vehicles have the same load capacity.
(6) Consumers always accept the delivered goods, whether they are satisfied with the delivery speed or not.
(7) Consumer satisfaction is only affected by the delivery time.
(8) When disruptions occur, the vehicle location becomes a virtual distribution center, while the original distribution center becomes the terminal.

B. SYMBOLS

Let $V = \{v_0, v_1, v_2, \cdots, v_n\}$ be the set of locations, which v_0 is the distribution center and $v_1 \ldots v_n$ are the n consumers. The distribution cost and travel time from v_i to v_j are respectively denoted as C_{ij} and t_{ij}. The demand, service time and time window of v_i are respectively denoted as q_i, w_i and $[ET_i, LT_i]$, where $[ET_i]$ and $[LT_i]$ are the earliest and latest arrival times, respectively.

Let $K = \{v_{m+1}, v_{m+2}, \cdots, v_{m+K}\}$ be the set of vehicles, where $v_{m+1} \ldots v_{m+K}$ are the K vehicles and m is the number of unfinished delivery tasks. The load capacity and arrival time of the vehicle are denoted as Q and t_i, respectively.

Let DS_i be the set of unserved consumers. The dissatisfactions of consumer, driver and operator (of the distribution center) are respectively denoted as D_{Pi}, D_{Ni} and D_{Fi}.

The route error is denoted as t_{ijk}. The route error equals -1 if the route is in the original plan, 1 if the route is in the new plan, and 0 if the route is not in either plan.

Two control parameters x_{ijk} and y_{ik} were defined. If vehicle K moves from v_i to v_j, x_{ijk} is 1; otherwise, x_{ijk} is 0. If v_i is served by vehicle K, y_{ik} is 1; otherwise, y_{ik} is 0.

The distribution cost is denoted as Z. The serial number of nodes are denoted as i and j.

C. INITIAL DISTRIBUTION MODEL

The initial logistics distribution model of the VRP can be established as:

$$\min Z \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{K} C_{ij} x_{ijk} \tag{1}$$

$$\sum_{i=1}^{n} q_i y_{ik} \le Q \tag{2}$$

$$\sum_{k=1}^{K} y_{0k} \le K \tag{3}$$

$$\sum_{k=1}^{k} y_{ik} = 1, \quad i = 1, 2, 3, \cdots, n \tag{4}$$

$$\sum_{i=1}^{n} x_{i0k} = 1, \quad k = 1, 2, 3, \cdots, K \tag{5}$$

$$\sum_{i=0}^{n} x_{ijk} = y_{jk}, \quad j = 1, 2, 3, \cdots, n, \quad k = 1, 2, 3, \cdots, K \tag{6}$$

$$\sum_{j=0}^{n} x_{ijk} = y_{jk}, \quad i = 1, 2, 3, \cdots, n, \quad k = 1, 2, 3, \cdots, K \tag{7}$$

$$\sum_{k=1}^{K} \sum_{i=0}^{n} x_{ijk} \left(t_i + w_i + t_{ij}\right) = t_j, \quad j = 1, 2, 3, \cdots, n \tag{8}$$

$$t_i \ge ET_i \quad i = 1, 2, 3, \cdots, n \tag{9}$$

$$t_i + w_i \le LT_i \quad i = 1, 2, 3, \cdots, n \tag{10}$$

Equation (1) specifies the objective of the model, which is minimal distribution cost. Equation (2) requires that no vehicle should be overloaded. Equation (3) ensures that each vehicle must leave from the distribution center. Equation (4) demands that all consumers should be served, and that each consumer can only be served by one vehicle. Equation (5)

TABLE 1. Evaluation index system for consumer value.

Primary level	Secondary level
Current value A_1	Service charge B_1
	Mean service charge B_2
	Delivery time B_3
	Profit margin B_4
Potential value A_2	Age B_5
	Income B_6
	Education level B_7
	Demand increment B_8
Relationship value A_3	Satisfaction B_9
	Relationship-building time B_{10}
	Recommendation B_{11}

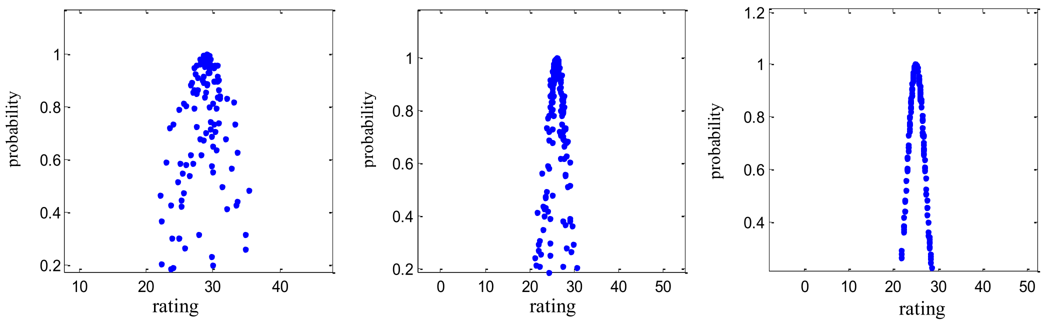

FIGURE 1. Expert ratings on the service charge.

TABLE 2. The final ratings on the secondary indices.

Secondary level	Rating
Service charge B_1	25
Mean service charge B_2	17
Delivery time B_3	8
Profit margin B_4	5
Age B_5	11
Income B_6	6
Education level B_7	7
Demand increment B_8	5
Satisfaction B_9	8
Relationship-building time B_{10}	3
Recommendation B_{11}	5

stipulates that the vehicle must return to the distribution center after completing the delivery. Equations (6)~(8) describe the relationship between different variables. Equations (9) and (10) set out the time window requirements of the consumers.

D. EVALUATION OF CONSUMER VALUE

Consumer value provides a criterion for consumer classification and lays the basis for disruption management. In this paper, the consumer value is determined by expert evaluation and the cloud model, and then the consumers are classified by the cloud model based on the consumer value.

1) EVALUATION INDEX SYSTEM FOR CONSUMER VALUE

To evaluate consumer value, an index system was built up (Table 1), involving 3 primary indices and 11 secondary indices. The three primary indices reflect the three dimensions of consumer value. Among them, the relationship value was introduced to demonstrate the importance of consumer relations to logistics enterprises.

2) RATING OF EVALUATION INDICES

Each index was given a rating determined by ten experts, which was modified iteratively as per the actual situation of the consumer. Taking the service charge for instance, the ratings of the index were corrected round after round based on the ratings given in the previous round. This process terminates only if all experts agree on the index rating. After each round, the expectation, entropy and hyper-entropy were derived by the backward cloud generator. Figure 1 shows the expert ratings on the service charge in each round. Table 2 shows the final ratings on the secondary indices.

3) CONSUMER CLASSIFICATION

The consumers were classified by the cloud model. Let $V = (v_1, v_2, v_3)$ be the set of target consumers. As mentioned above, the expectation, entropy and hyper-entropy were obtained by the backward cloud generator. The membership of each consumer was determined by the X-conditional cloud generator. On this basis, the set of target consumers was divided into $v_1 = (85-100)$ key consumers, $v_2 = (40-85)$ general consumers and $v_3 = (0-40)$ unimportant consumers. The classification results are plotted as Figure 2 below.

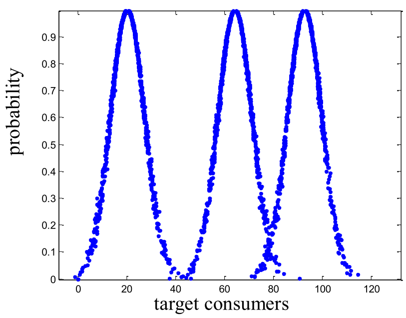

FIGURE 2. **The classification results.**

E. EXTRACTION AND MEASUREMENT OF DISRUPTION FACTORS

In this paper, the disruption of logistics distribution system is measured by the dissatisfactions of consumer, driver and operator. The penalty function $P_i(t_i)$ of consumer satisfaction, which can be determined by both soft and hard time windows, can be expressed as:

$$P_i(t_i) = \begin{cases} M & t_i \le EC_i \text{ or } t_i \ge LC_i \\ a_i (EC_i - t_i)^{m_i} & EC_i \le t_i \le ET_i \\ 0 & ET_i \le t_i \le LT_i \\ b_i (t_i - LC_i)^{n_i} & LT_i \le t_i \le LC_i \end{cases} \quad (11)$$

where, M is an infinite number; a_i, b_i, m_i and n_i are all penalty coefficients. EC_i and LC_I are respectively the earliest and latest delivery times the consumer can tolerate.

Consumer dissatisfaction can be derived from the above equation:

$$D_P = \sum\nolimits_{i\in DS\cap Z_1} \alpha \cdot P_i(t_i) + \sum\nolimits_{i\in DS\cap Z_2} \beta \cdot P_i(t_i) + \sum\nolimits_{i\in DS\cap Z_3} \gamma \cdot P_i(t_i) \quad (12)$$

where, Z_1, Z_2 and Z_3 are the three levels of consumers, respectively. α, β, and γ are indicate value of key consumers, value of general consumers and value of unimportant consumers, respectively.

The operator dissatisfaction was described by its direct cause, the distribution cost deviation:

$$D_F = \sum\nolimits_{k\in K} \sum\nolimits_{i\in RT} \sum\nolimits_{j\in RT} c_{ij} t_{ijk} \quad (13)$$

The driver dissatisfaction was also depicted by its primary cause, the route error:

$$D_N = \sum\nolimits_{k\in K} \sum\nolimits_{i\in RT} \sum\nolimits_{j\in RT} |t_{ijk}| \quad (14)$$

On this basis, a lexical order disruption management model can be established as:

Objective function:

$$\min \text{Lex} = (P_1 : D_P, P_2 : D_F, P_3 : D_N) \quad (15)$$
$$\text{s.t. } P_1 \ge P_2 \ge P_3 \quad (16)$$

III. IMPROVED TSA

The TSA is a new swarm intelligence optimization algorithm. It has been widely applied to tackle complex problems, such as estimating frequency modulated parameters, solving traveling salesman problem (TSP) and dispatching disaster relief materials. In this paper, the TSA is improved by the IA to solve the disruption management for the VRP. Thus, the improved algorithm is denoted as the IATSA. In the IATSA, each tree represents a parent individual and each seed represents a child individual generated of a parent tree. Through the evolution, the seeds around the parent tree always obey the normal distribution.

The main parameters of the algorithm are defined as follows: the position of each seed $X = \{x_1, x_2, x_3, \cdots, x_n\}$, the population size N_1, the number of seeds N_2, the number of trees N_3, the maximum number of iterations N_4, the parent distance thresholds D_{12}, D_{13} and D_{23}, the mean and variance of normal distribution μ and δ^2, the optimal tree of each iteration P_i, the best-known global optimal tree G.

A. ADAPTIVE EXTRACTION OF SEED INFORMATION

The seed information can be extracted adaptively by:

$$P_c = \begin{cases} 1 & f' \ge \bar{f} \\ (\bar{f} - f') / (f_{max} - f') & f' \le \bar{f} \end{cases} \quad (17)$$

where, f_{max} is the maximum known fitness; $\bar{f}$ is the mean fitness of trees; f' is the fitness of the tree for crossover. The probability of information extraction is constantly adjusted based on the fitness of the tree. The probability is one if the tree's fitness is above average, and relatively low if otherwise.

B. ADAPTIVE CONTROL OF SEED EVOLUTION

In the IATSA, the position of the inoculation point is controlled based on the fitness of the tree. The length of the seed population to be inoculated can be computed as:

$$l_1 = f_2 l / (f_1 + f_f)$$
$$l_2 = l - l_2 \quad (18)$$

where, f_1 is the fitness of the optimal tree; f_2 is the fitness of the seed to be inoculated; l is the length of the seed population; l_2 is the length of the tree population to be inoculated. The value of l_2 is positively correlated with the fitness of the optimal tree.

The flow chart of the IA-SOA is shown in Figure 3 below.

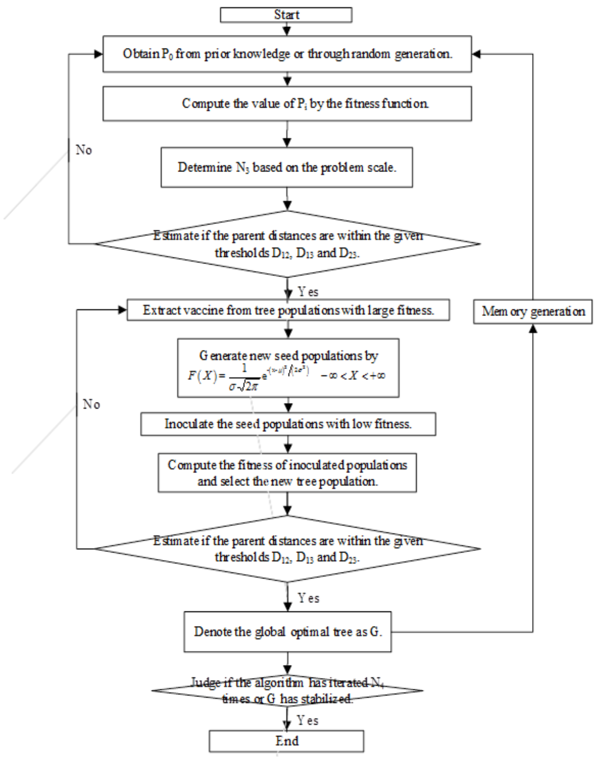

FIGURE 3. **The flow chart of IASOA.**

IV. SIMULATION

A. DATA SOURCE

The proposed model and algorithm were applied to simulate the logistics distribution between 1 distribution center (Handan Cigarette Distribution Centre, Hebei, China) and 24 consumers. The position coordinates and other information of all nodes (the center and the consumers) are listed in Tables 3 and 4 below.

B. DATA PROCESSING

Four vehicles were assumed to complete the distribution task. The consumers were divided into three levels based on the evaluation of ten experts. The values of the consumers rated by the experts are listed in Table 5.

The mean rating of each consumer was taken as the final consumer value. The parameters of the IATSA are listed in Table 6.

The expectation, entropy and hyper-entropy of each consumer were obtained by backward cloud generator (Table 7).

The consumers of the distribution centre were divided into three levels by the cloud model. The memberships of the consumers are given in Table 8.

When the distribution process ran to 10:45, the time window was changed as shown in Table 9.

C. RESULTS ANALYSIS

Both the IATSA and the original TSA were adopted to solve the disruption management model. The solutions are as follows.

1) THE SOLUTION OF THE IATSA

The mean consumer satisfaction was 88.22 %, the total route error was 10, and the delivery cost deviation was 71 yuan. The vehicle routing plan of the IATSA is presented in Table 10 and Figure 4.

2) THE SOLUTION OF THE TSA

The mean consumer satisfaction was 75.74 %, the total route error was 12, and the delivery cost deviation was 82 yuan.

TABLE 3. **Consumer information.**

Serial No.	X-axis coordinate /km	Y-axis coordinate /km	Demand / piece	Service time /min	Time window /h
1	96	42	22	7	[7:00-10:00]
2	99	23	31	10	[7:00-8:55]
3	100	46	37	12	[7:00-9:05]
4	102	41	36	11	[10:00-13:45]
5	72	52	19	8	[8:00-9:00]
6	75	25	25	9	[10:00-12:00]
7	90	17	30	10.5	[8:00-10:00]
8	50	27	23	8.5	[13:00-18:00]
9	44	23	41	16	[12:10-18:00]
10	116	26	42	16	[8:00-18:00]
11	135	11	31	10	[8:00-10:00]
12	103	56	36	11	[12:15-18:00]
13	141	21	29	9.5	[12:00-18:00]
14	93	4	33	12	[7:00-18:10]
15	62	40	31	11	[12:00-16:00]
16	40	50	33	12	[8:20-18:00]
17	41	13	27	9.5	[8:00-9:40]
18	22	35	48	20	[7:10-9:40]
19	140	56	41	16	[7:10-10:45]
20	142	37	25	9	[8:10-18:00]
21	70	8	21	8	[10:05-13:10]
22	13	18	45	18	[10:30-11:00]
23	33	53	18	7.5	[10:00-17:30]
24	133	11	30	10	[10:30-12:00]

TABLE 4. Distance between the nodes.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	0	3	6	6	7	27	30	29	19	32	29	31	17	47	3	7	4	36	7	8	47	51	65	68	79
1	3	0	3	6	4	29	29	26	16	30	26	29	20	48	3	4	7	33	9	6	45	49	66	68	76
2	6	3	0	8	3	31	28	24	13	29	24	28	23	48	6	1	10	30	11	6	43	46	67	68	74
3	6	6	8	0	6	33	35	32	21	37	26	26	16	41	9	8	5	35	13	4	42	47	71	62	74
4	7	4	3	6	0	33	31	26	15	32	22	25	22	45	8	2	9	30	13	3	41	44	70	65	72
5	27	29	31	33	33	0	27	40	37	30	54	58	31	71	26	32	28	57	20	34	74	77	41	92	105
6	30	29	28	35	31	27	0	17	22	3	43	53	45	76	27	29	34	39	26	34	66	65	46	95	93
7	29	26	24	32	26	40	17	0	11	16	29	42	46	67	26	24	33	23	29	29	52	49	62	86	77
8	19	16	13	21	15	37	22	11	0	22	21	32	36	56	17	13	23	21	21	17	44	43	66	75	72
9	32	30	29	37	32	30	3	16	22	0	43	54	47	77	29	30	36	38	28	35	66	64	47	97	93
10	29	26	24	26	22	54	43	29	21	43	0	15	41	42	29	23	31	14	35	22	23	23	87	59	52
11	31	29	28	26	25	58	53	42	32	54	15	0	37	27	33	27	30	29	38	24	17	24	95	44	49
12	17	20	23	16	22	31	45	46	36	47	41	37	0	42	20	23	13	51	19	20	53	60	71	62	85
13	47	48	48	41	45	71	76	67	56	77	42	27	42	0	50	47	44	57	54	42	32	44	112	20	57
14	3	3	6	9	8	26	27	26	17	29	29	33	20	50	0	6	7	35	6	9	48	52	63	70	80
15	7	4	1	8	2	32	29	24	13	30	23	27	23	47	6	0	10	30	12	5	42	45	68	67	73
16	4	7	10	5	9	28	34	33	23	36	31	30	13	44	7	10	0	39	9	9	47	52	68	65	79
17	36	33	30	35	30	57	39	23	21	38	14	29	51	57	35	30	39	0	40	31	33	27	85	72	55
18	7	9	11	13	13	20	26	29	21	28	35	38	19	54	6	12	9	40	0	15	54	57	58	74	85
19	8	6	6	4	3	34	34	29	17	35	22	24	20	42	9	5	9	31	15	0	40	44	72	62	71
20	47	45	43	42	41	74	66	52	44	66	23	17	53	32	48	42	47	33	54	40	0	12	110	42	32
21	51	49	46	47	44	77	65	49	43	64	23	24	60	44	52	45	52	27	57	44	12	0	110	53	29
22	65	66	67	71	70	41	46	62	66	47	87	95	71	112	63	68	68	85	58	72	110	110	0	132	139
23	68	68	68	62	65	92	95	86	75	97	59	44	62	20	70	67	65	72	74	62	42	53	132	0	55
24	79	76	74	74	72	105	93	77	72	93	52	49	85	57	80	73	79	55	85	71	32	29	139	55	0

TABLE 5. Expert evaluation results.

Serial No.	Key consumer	General consumer	Unimportant consumer	Σ
Expert 1	0.5	0.3	0.2	1
Expert 2	0.4	0.4	0.2	1
Expert 3	0.6	0.3	0.1	1
Expert 4	0.7	0.2	0.1	1
Expert 5	0.5	0.3	0.2	1
Expert 6	0.4	0.3	0.3	1
Expert 7	0.5	0.3	0.2	1
Expert 8	0.6	0.2	0.2	1
Expert 9	0.5	0.3	0.2	1
Expert 10	0.4	0.4	0.2	1

TABLE 6. Parameter settings.

Parameters	Meaning	Numerical value
N_1	Population size	50
N_2	Number of seeds	3
N_3	Number of trees	3
N_4	Number of maximum iterations	100
D_{31}	Parent distance threshold	5.85
D_{32}	Parent distance threshold	7.91
D_{21}	Parent distance threshold	4.63
μ	Mean of normal distribution	2.16
δ^2	Variance of normal distribution	0.44
Q	Vehicle capacity (unit: pieces)	210
a_i	Time window coefficient	0.02
b_i	Time window coefficient	0.02
m_i	Time window coefficient	0.01
n_i	Time window coefficient	0.01
α	Value of key consumer	0.51
β	Value of general consumer	0.3
γ	Value of unimportant consumer	0.19

TABLE 7. Cloud model indices of consumers.

Serial No.	Numerical features		
	Ex	En	He
1	78.21	2.34	0.25
2	95.23	2.07	0.51
3	62.54	3.19	0.69
4	81.55	1.93	0.32
5	57.24	2.45	0.67
6	73.12	2.78	0.44
7	76.38	1.90	0.31
8	84.75	2.32	0.38
9	77.90	2.36	0.36
10	87.26	1.32	0.81
11	88.27	2.13	0.45
12	63.78	1.56	0.28
13	88.37	1.89	0.58
14	88.36	1.77	0.52
15	62.56	1.43	0.31
16	78.87	2.21	0.25
17	60.11	1.56	0.24
18	82.55	1.73	0.34
19	53.24	2.42	0.57
20	87.29	1.31	0.80
21	93.23	2.57	0.31
22	88.26	2.12	0.42
23	63.54	3.17	0.66
24	87.23	1.31	0.71

The vehicle routing plan of the TSA is presented in Table 11 and Figure 5.

According to the above results, it can be seen that the mean consumer satisfaction outputted by the IATSA was 12.48 % higher than that of the original TSA. Obviously, the route error of the IATSA was 16.67% lower than that of the TSA. It can be observed that the distribution cost deviation of the IATSA was 13.41 % lower than that of the TSA. Figure 4 shows the routing plan of enterprise obtained by the IATSA. The consumers and paths of each vehicle are listed. The first routing is 0-17-9-22-18-8. The second is 0-23-16-15-5. The third is 0-19-3-12-20. The fourth is 0-10-24-14-21.Figure 5 shows the routing plan of enterprise obtained by the IATSA.

TABLE 8. The memberships of the consumers.

Serial No.	Simulated value			Classification result
	Key consumer	General consumer	Unimportant consumer	
1	0	7	3	General consumer
2	10	0	0	Key consumer
3	0	8	2	General consumer
4	0	10	0	General consumer
5	0	0	10	Unimportant consumer
6	8	2	0	Key consumer
7	0	9	1	General consumer
8	1	9	0	General consumer
9	0	7	3	General consumer
10	0	1	9	Unimportant consumer
11	0	2	8	Unimportant consumer
12	9	0	1	Key consumer
13	2	8	0	General consumer
14	0	8	2	General consumer
15	1	8	1	General consumer
16	1	7	2	General consumer
17	2	8	0	General consumer
18	9	1	0	Key consumer
19	0	1	9	Unimportant consumer
20	1	9	0	General consumer
21	3	7	0	General consumer
22	9	0	1	Key consumer
23	1	2	7	Unimportant consumer
24	3	6	1	General consumer

TABLE 9. Distance between the nodes.

No. of disrupted nodes	Original time window	New time window
3	[7:00-9:05]	[12:10-18:00]
9	[12:10-18:00]	[9:10-11:00]
16	[8:20-18:00]	[15:00-18:00]

The consumers and paths of each vehicle are listed. The first routing is 0-17-9-22-18-8. The second is 0-15-6-23-5. The third is 0-3-12-19-20. The fourth is 0-14-24-10-21.

The convergence curves of the consumer satisfaction, the route errors and distribution cost deviations by the IATSA and the TSA are shown in Figure 6, Figure 7, Figure 8, respectively.

Figure 6, Figure 7, Figure 8 all show that the IATSA converges faster than the TSA. Compared with the basic TSA, the IATSA can not only improve the convergence speed, but also improve consumer satisfaction, reduce the route errors and the distribution cost deviation. It provides a theoretical basis for the enterprises, which want to improve consumer satisfaction, reduce the route errors and the distribution

TABLE 10. Vehicle routing plan of the IATSA.

Serial No.	Consumer satisfaction	Route error	Distribution cost deviation /yuan
Route 1	83.32 %	4	28.4
Route 2	77.14 %	0	0
Route 3	78.62 %	2	14.2
Route 4	81.78 %	4	28.4

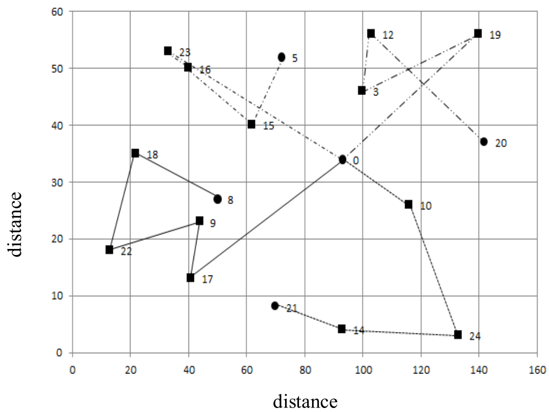

FIGURE 4. The vehicle routing plan of the IATSA.

TABLE 11. Vehicle routing plan by the TSA.

Serial No.	Consumer satisfaction	Route error	Distribution cost deviation /yuan
Route 1	83.32 %	4	27.4
Route 2	72.14 %	4	27.4
Route 3	76.53 %	0	0
Route 4	70.98 %	4	27.4

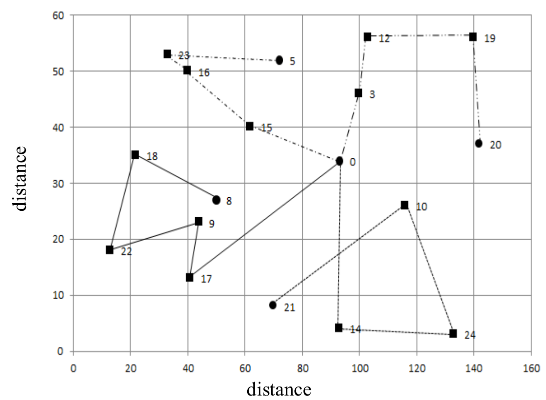

FIGURE 5. The vehicle routing plan of the TSA.

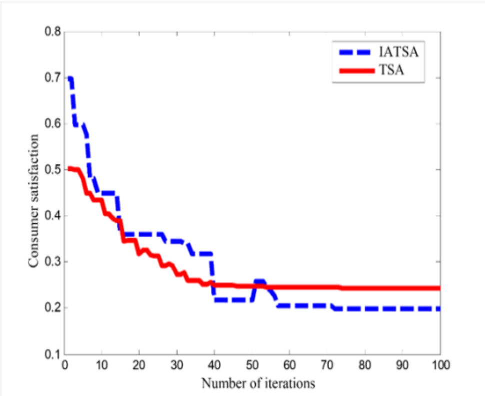

FIGURE 6. Convergence curves of consumer satisfaction.

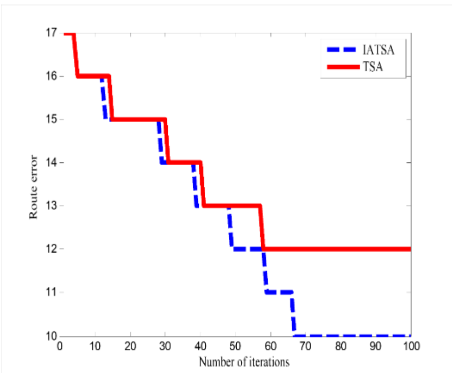

FIGURE 7. Convergence curves of route error.

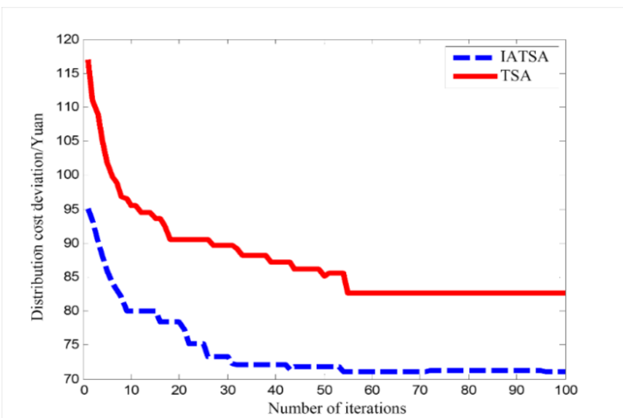

FIGURE 8. Convergence curves of distribution cost deviation.

cost deviation. To sum up, the proposed IATSA outperformed the original TSA in all three aspects, indicating that it could mitigate disruptions in logistics distribution excellently.

V. CONCLUSION

Considering the lack of research on consumer value in logistics distribution, this paper explores deep into consumer relationship, cloud model and disruption management, and relies on the cloud model to classify the target consumers based on their values. On this basis, the author set up a distribution management model for the VRP. To solve this model, the TSA was improved with the IA and proved valid through simulation. Some of the parameters were empirically designed, and will be improved in future research.

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