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Modeling and solving method of logistics collaborative distribution problem involving crowdsourcing mode under compensation incentive strategy

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ABSRTACT. *Crowdsourcing logistics participating in distribution can reduce the cost of logistics distribution. In order to ensure the timeliness of distribution and make full use of social underused assets, crowdsourcing logistics is introduced into traditional distribution for collaborative distribution to reduce logistics transportation costs. In order to improve the enthusiasm of occasional drivers and better reduce the cost of logistics companies, different incentive strategies are proposed for occasional drivers, and a dynamic compensation plan is proposed based on the static compensation plan. The solution is solved by a two-stage method. The first stage allocates orders to the occasional drivers based on the fuzzy integral evaluation model, and the second stage sends the orders not delivered by the occasional drivers to the logistics company for distribution and route planning, using genetic algorithms and simulated annealing algorithm combined with memory simulated annealing algorithm to solve. The results show that the dynamic compensation scheme further affects the transportation cost of logistics by influencing the enthusiasm of occasional drivers, and the appropriate compensation scheme can reduce the transportation cost of logistics to a greater extent.*

KEYWORDS: *crowdsourcing logistics;collaborative distribution, compensation plant, fuzzy integral evaluation model,genetic algorithm,simulated annealing algorith*

1. Introduction

Technological advances in the past decades,such as smart phones and mobile devices,have been a catalyst for the so called sharing economy. The sharing economy makes underused assets becomes wealth, coupled with the driving factors of the logistics industry itself, use the sharing economy to reduce logistics costs and improve distribution efficiency has become the direction of innovation in the logistics industry. Among them, WalMart and Amazon first put forward the concept of "crowdsourcing logistics", so that ordinary people, not just employees hired by logistics companies, can collaborate with logistics companies for delivery.

Occasional drivers participating in the last mile delivery has many potential benefits.Logistics companies can reduce transportation costs by introducing crowdsourcing, and they can also reduce vehicle demand by using crowdsourcing vehicles during peak hours, reduce service costs, and improve customer satisfaction.The introduction of crowdsourced vehicles can largely utilize the existing resources on the road, reduce road congestion and reduce carbon dioxide emissions.We mainly study the impact of dynamic compensation schemes on occasional drivers and the impact on order distribution, and further study the impact of the introduction of crowdsourced vehicles on logistics distribution costs.

The participation of occasional drivers in collaborative delivery is a new variant of the vehicle routing problem with time windows. Logistics companies build distribution routes based on order information and delivery time, and use occasional driver resources as much as possible, because the distribution cost of crowdsourced vehicles is lower than traditional distribution costs. The logistics company want to minimize the cost of delivery, and occasional drivers are willing to take a detour to serve one transportation requests for as much as compensation.This article explores the impact of crowdsourced logistics participation on distribution costs under different compensation schemes.

The related body of literature for this paper can be split into this parts：Firstly the vehicle routing problem is also called the VRP problem, which is widely studied in the logistics field.The research on vehicle routing problems involves classic VRP problems, VRP problems with time windows and GVRP problems with the theme of protecting the environment.Among them, Fan Houming [1] put forward the VRP problem of fuzzy demand, which fuzzed customer demand and solved it through an improved genetic algorithm.J.Andelmin and E.Bartolini[2]solved the path problem of green vehicles through heuristic local search algorithm and local heuristic algorithm using multiple reconstruction graph reconstruction. Secondly, the research on crowdsourcing logistics.Wang Wenjie [3] et al. established a dynamic pricing model for crowdsourcing services under random demand based on social distribution supply attributes and accumulated loss order costs, indicating that the rate of return has an impact on crowdsourcing service pricing and revenue. Mu Jing [4] studied instant delivery and revenue incentives and established a capacity scheduling model, showing the feasibility and effectiveness of this model in improving the enthusiasm of logistics personnel and ensuring customer satisfaction. Thirdly, research on the Participation of Crowdsourcing Logistics in Collaborative Distribution. Among them, Claudia Archetti, Martin Savelsbergh [5] proposed the use of crowdsourcing vehicles to participate in the distribution research, but did not consider the delivery time window, which has strong limitations. Lars Dahle, Henrik Andersson [6] studied the picking and delivery problems of occasional drivers with time windows, and proposed the impact of different compensation schemes on delivery efficiency and customer satisfaction. However, its compensation scheme

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focuses on a static single compensation scheme, and does not consider a dynamic compensation scheme.

In the above mentioned literature on the collaborative distribution research of logistics companies and crowdsourced vehicles, when calculating the cost, there are few literatures that take into account the salary issue of logistics company distribution staff, and do not consider the enthusiasm of occasional drivers to be affected by compensation. Therefore, this time we mainly study the impact of different compensation schemes on the collaborative distribution of crowdsourcing vehicles and logistics companies. By introducing crowdsourcing vehicles to participate in logistics distribution, we will reduce the number of distribution personnel of logistics companies, improve the utilization rate of logistics distribution resources, and realize New planning for distribution.

2. Problem description and formulation

In this section the problem we study Vehicle Routing Problem With Occasional Drivers (VRPOD) .The VRPOD consists of a set of pickup nodes I,I={1,2,3,......m}and a corresponding set of delivery nodes J={m+1,m+2,......m+n}, where transportation request i consists of transporting a quantity L i from pickup node i to delivery node n + i and V=I∪J, 0 point is the starting point of logistics company regular vehicles, A homogeneous fleet of regular vehicles K^R , and a fleet of occasional drivers K^O , are available to service the requests. Each vehicle k $\in K = K^R \cup K^O$ and each K^O has an origin o(K^O) and a destination d(K^O). For each node i ∈ I there is a time window [ET_j,LT_j] within which it must be serviced.E={(i,j)|i,j∈V}, The distribution cost of a logistics company consists of the salary of the drivers and the cost of distribution, Calculation of distribution cost from i to j c_{ijk}, $k \in K$,The arrival time of the vehicle is Tjk,k∈K,$K = K^R \cup K^O$, The service time is tjk,The vehicle capacity is Q_q,q=A,B,C,when q=A, on behalf of logistics companies vehicles,when q=B,C,on behalf of occasional vehicles, represents three different types of vehicles.l_{ik} represents the load of vehicle k at node i,d_j represents the demand at point j, We assume that the regular vehicles of the logistics company will start from the distribution center and then return to the distribution center. Each vehicle of the logistics company can complete the distribution of multiple orders without conflicting time windows. When selecting occasional vehicle delivery, the destination location d(KO) of the crowdsourced vehicle to the location of the delivery point j must be satisfied $d_{(jk)} < \varepsilon$(ε is a constant), and the occasional vehicle is eligible for delivery.β_{ijk} Represents whether the order is delivered from i to j by occasional vehicle k,w_{ijk} indicates whether crowdsourcing vehicle k applies to deliver order j,defining the compensation fuction $f_{K^O}(x)$ for occasional driver, Where x stands for the value of β_{ijk}. C is the salary of distribution personnel in logistics company, which is a constant. We assume that

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occasional drivers can only deliver one order. According to the above parameters, the mathematical model is established as follows:

$$\min \sum_{k\in K^R}\sum_{j\in I} C.x_{0jk} + \sum_{k\in K^R}\sum_{i\in D} c_{ijk}.x_{ijk} + \sum_{k\in K^O} f_{K^O}(x) \quad (1)$$

$$\sum_{j=V\cup\{d(K^O)\}} x_{o(K^O)jk} = 1 \quad k\in K \quad (2)$$

$$\sum_{i\in V\cup\{o(K^O)\}} x_{ijk} - \sum_{i\in V\cup\{d(K^O)\}} x_{jik} = 0 \quad k\in K \quad i\in D \quad (3)$$

$$\sum_{i=J\cup\{o(K^O)\}} x_{o(K^O)jk} = 1 \quad k\in K \quad (4)$$

$$\sum_{k=K}\sum_{j=D} x_{ijk} = 1 \quad i\in I \quad (5)$$

$$\sum_{i\in I}\sum_{j\in D} x_{ijk} - \sum_{i\in I}\sum_{j\in D} x_{j,m+i,k} = 0 \quad k\in K \quad (6)$$

$$\beta_{ijk} \le \omega_{ijk} \quad i\in I \quad j\in J \quad k\in K^O \quad (7)$$

$$\sum_{i\in I}\sum_{k\in K^O}\beta_{ijk} \le 1 \quad j\in J \quad (8)$$

$$\sum_{i\in I}\sum_{k\in K^O}\beta_{ijk} + \sum_{i\in D}\sum_{k\in K^R} x_{ijk} = 1 \quad j\in J \quad (9)$$

$$T_{ik} + t_{i,n+i} \le T_{n+i,k} \quad k\in K \quad i\in J \quad (10)$$

$$(l_{ik} + L_j - l_{jk})x_{ijk} = 0 \quad i\in V \quad i\in J \quad k\in K^R \quad (11)$$

$$L_i \le l_{ik} \le Q_q \quad i\in D \quad k\in K \quad (12)$$

$$f_{K^O}(x) = R^C_{K^O}(1 - x_{o(k)d(k)k}) + R^r_{K^O}\left(\sum_{i\in I}\sum_{j\in J} c_{ijk}x_{ijk} - C_{o(k)d(k)k}\right) \quad k\in K^O \quad (13)$$

$$x_{ijk} = \{0,1\} \quad (14)$$

$$\beta_{ijk} = \{0,1\} \quad (15)$$

$$\omega_{ijk} = \{0,1\} \quad (16)$$

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The objective function (1) minimizes the routing cost of the regular vehicles plus the compensations given to the ODs. Constraints (2) and (4) make sure that a vehicle exits its origin and enters its destination. Constraints(3) ensure that the flow isbalanced from origin to destination. Furthermore, constraints (5) force every pickup operation to be performed by exactly one vehicle, and constraints (6) state that a vehicle that picks up a request also delivers it. Constraint condition (7) indicates whether the vehicles participating in crowdsourcing distribution are qualified for distribution. Constraints (8) indicates that occasional drivers who are selected to participate in order distribution decide whether to deliver; constraints (9) indicates that an order can only be delivered once; constraints (10) refers to order distribution sequence; constraints(11) refers to vehicle capacity limit of logistics company; constraints (12) indicates that the weight of distribution cannot exceed the maximum capacity of distribution vehicle Quantity, constraints (13) denotes the dynamic reward of crowdsourcing drivers. The formula indicates that if the occasional vehicles participate in the distribution, the basic cost is a piecewise function, and the cost is determined according to the time of order delivery. If the occasional vehicle K is not used, the value is 1, otherwise the value is 0. Is the compensation coefficient given by participating in distribution. Constraints(14), (15), (16)define the variables.

3. Algorithm and solution

Compared with the classical VRP Problem, the VRPOD problem takes the occasional driver into account, which is influenced by many factors, and the two-stage method is used to solve it. In the first stage, the fuzzy integral evaluation model is used to get the orders delivered by occasional drivers. In the second stage, the improved genetic algorithm combined with simulated annealing algorithm is used to optimize the distribution path.

3.1 Fuzzy integral evaluation model

When introducing the crowdsourcing model in the traditional delivery method, this article takes into account that crowdsourcing can participate in the distribution flexibly. The distribution process depends largely on the occasional driver himself. In order to make the occasional driver better utilize his distribution advantages, chooses the best occasional driver for distribution, a fuzzy integral evaluation model is used to evaluate r drivers applying for crowdsourcing services, and the best crowdsourcing vehicles are selected to complete the delivery task. M is a set of screening indicators, which respectively represent the distribution cost, customer satisfaction and historical service quality of the crowdsourcing logistics party. For any $m_p \in M$, $M\lambda(V_p)$, (λ is the degree of fuzzy testing) is the weight of M in the test index set V_p. When λ is equal to 0, the three indicators are independent of each other. When λ is not equal to 0, there is a mutual relationship between the

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indicators. The fuzzy measures of the three indicators λ of the candidate occasional drivers are:

$$M_\lambda(V_3)=M(\{v_1, v_2, v_3\})=\sum_{p=1}^{3}M(v_p)+\lambda\sum_{p=1}^{2}\sum_{s=p+1}^{3}M(v_p)\cdot M(v_s)$$
$$+\lambda^2 M(v_1)\cdot M(v_2)\cdot M(v_3)\quad \lambda\neq 0 \tag{17}$$

Fuzzy integral is a nonlinear evaluation function that comprehensively considers the importance of indicators and their relationships, and is suitable for handling subjective evaluation problems. For the index value of each candidate crowdsourcing logistics, $h(v_p)$ represents the performance strength of the candidate under a specific evaluation index; $M(a_i)$ for the weight of each evaluation index value, A=V={a1, a2, a3}, fuzzy integral is fuzzy The generalized inner product of the membership function h(V) and the fuzzy measure function M(A) of the set:

$$\int h(V)dM(A)=h(V_3)M_\lambda(A_3)+[h(V_2)-h(V_3)]$$
$$+M_\lambda(A_2)+[h(v_1)-h(v_2)]M_\lambda(A_1) \tag{18}$$

Through fuzzy points, the evaluation index value of each occasional vehicle application driver can be determined, and its comprehensive operation capability can be evaluated, and finally the best crowdsourced distribution operation plan can be selected.

3.2 Simulated annealing algorithm with memory

In path planning, combining the advantages of genetic algorithm and simulated annealing algorithm create a new algorithm with memory to function corresponding to the vehicle routing problem is proposed. Specific steps are as follows:

(1) Chromosome construction. This model is a vehicle scheduling model. In order to simplify the calculation and facilitate the handling of the VRP problem of vehicle scheduling, this paper directly uses natural number coding. The solution vector in the mathematical model is compiled into a chromosome of length k+M+1. ip represents the p delivery point. The number of 0 is M+1, and all 0 represent the distribution center. The natural number code is divided into M sections to form M subroads, which means that M vehicles perform all tasks.

(2) The creation of the initial population. Randomly generate popsize chromosomes with length l (l is the number of demand points) as the initial population, and each chromosome is a random sequence composed of a sequence number corresponding to the demand point. The size of the population is between 10 and

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100. Randomly generate k full permutations, and then insert M+1 0 into the chromosome randomly. There must be two 0 at the head and tail, and there cannot be two consecutive 0 in the chromosome .

(3) Initial temperature determination and de-temperature operation. The initial temperature is determined in the form of selection, where k is a large enough number, f_{max} is the largest objective function value in the initial population, and f_{min} is the smallest objective function value in the initial population.

(4) Calculate fitness function. Take the total cost of delivery by the logistics company as the fitness function.

(5) Selection, crossover operator. Use proportional selection operator. This operator is a random revisiting sampling method, rotating the roulette popsize times, and the selected chromosomes reproduce the offspring according to the set crossover rate.

3.3 Case analysis

According to the research ideas of this paper and the characteristics of the model, the corresponding parameter settings are given, and use matlab to solve them. We assume that the order delivery time is between the interval of [0 60], that is, to simulate the one hour order delivery situation, and assume that the delivery rewards of crowdsourcing drivers are divided into fixed rewards and variable rewards.

Randomly generate 20 customer location information and 20 random vehicle location information through matlab. The randomly generated customer location is shown in Figure 1 below, the crowdsourced vehicle situation is shown in Table 2, and the vehicle type and capacity limits are shown in Table 3. Related parameter settings are shown in Table 4 and 5.

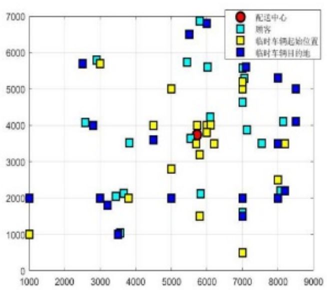

Figure.1 Basic situation distribution map

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Table1 Customer distribution map

Customer ID	Demand	Customer location		Time Window	
		x -axis	y -axis	ETj	LTj
0	0	5723	3742	0	60
1	4	8142	4106	15	41
2	3	5541	3637	16	31
3	0.7	5826	2121	13	31
4	1.5	7130	3875	13	31
5	2.4	2583	4077	14	38
6	3.2	3822	3520	8	19
7	2.9	7000	1604	15	32
8	2.6	7056	5295	0	25
9	1.3	2900	5788	0	12
10	1.1	3665	2127	5	35
11	1.9	6088	4224	6	40
12	0.3	5447	5739	7	34
13	1.7	3566	1045	6	26
14	1.8	7009	5582	18	44
15	2.1	7545	3508	8	34
16	2.2	3434	2044	3	22
17	2.5	6017	5607	30	55
18	3	5798	6866	20	47
19	1.8	6990	4633	11	40
20	1.7	8067	2206	8	22

Table2 Basic situation map of crowdsourced vehicles

Vehicle number	Vehicle Type	Starting position		Destination location	
		x -axis	y -axis	x -axis	y -axis
1	C	5700	3500	4500	3600
2	C	4500	4000	2500	5700
3	B	8000	2500	8000	3500
4	B	5800	3200	5000	2000
5	B	5723	4000	3200	1800
6	C	5000	2800	3000	2000
7	C	7000	5000	8000	2000
8	C	5800	1500	3500	1000
9	C	5000	5000	8500	4100
10	B	1000	1000	1000	2000
11	C	6000	4000	8200	2200
12	B	3800	2000	5500	6500
13	C	6100	4005	7100	5605
14	B	7000	5200	8000	5300
15	B	6000	6800	8500	5000
16	B	6200	3500	7000	2000
17	C	8200	3500	6000	6800
18	B	6000	3800	2800	4000
19	C	3000	5700	7000	1500
20	B	7000	500	3500	1000

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Table3 Vehicle capacity distribution map

Vehicle Model	capacity
A	8.6
B	5
C	2

Table4 Test parameters

C	c	ε	$R_{K^O}^{C}$
300	0.00058	10000	1.5

Table5 Different time period value of $R_{K^O}^{r}$

Time period	value
[0 20]	3
[20 40]	4
[40 60]	2

Using a combination of logistics companies and crowdsourced vehicles, the crowdsourced vehicles are simulated using fixed compensation and dynamic compensation schemes. When the compensation is a fixed value, the distribution of occasional vehicles and traditional logistics companies is as follows: As shown in 6 , the distribution details of occasional drivers are shown in Table 8, and the distribution details of logistics companies are shown in Table 9. When the compensation is dynamic, the distribution of occasional vehicles and traditional vehicles is shown in Table 7. The distribution of occasional vehicles under dynamic remuneration is shown in Table 10 below, and the details of vehicle distribution by traditional logistics companies are shown in Table 11.

Table6 Fixed compensation

Logistics companies delivery point	Occasional drivers delivery point
1 4 5 6 7 8 10 11 12 13 14 15 17 18 19	2 3 9 16 20

Table7 Dynamic compensation

Logistics companies delivery point	Occasional vehicle delivery point
4 6 8 10 11 12 15 17 18 19	1 2 3 5 7 9 13 14 16 20

When the occasional vehicle compensation is fixed value

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Table8 Occasional vehicle distribution under fixed value compensation

Vehicle number	Vehicle Type	Starting position		Destination location		Delivery point	compensation
		x -axis	y -axis	x -axis	y -axis		
1	C	5700	3500	4500	3600	2	3
2	C	4500	4000	2500	5700	9	3
4	B	5800	3200	5000	2000	3	3
5	B	5723	4000	3200	1800	16	3
11	B	6000	4000	8200	2200	20	3

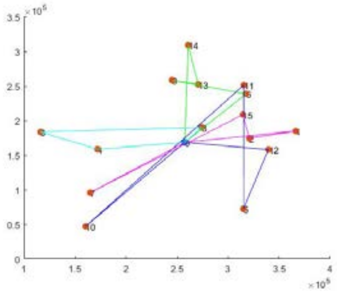

Figure.2 Fixed value compensation logistics companies distribution map

Table9 Fixed value compensation logistics companies distribution table

Vehicle number	Customer ID	Delivery route
1	4	0→18→17→12→8→0
2	4	0→13→14→7→15→0
3	3	0→6→5→11→0
4	4	0→1→4→19→10→0

Table10 Occasional vehicle distribution under dynamic value compensation

Vehicle number	Vehicle Type	Starting position		Destination location		Delivery point	compensation
		x -axis	y -axis	x -axis	y -axis		
1	C	5700	3500	4500	3600	2	5.12
2	C	4500	4000	2500	5700	9	5.86
4	B	5800	3200	5000	2000	3	7.07
5	B	5723	4000	3200	1800	16	4.49
8	C	5800	1500	3500	1000	13	5.01
9	C	5000	5000	8500	4100	1	4.57
11	C	6000	4000	8200	2200	20	8.79
13	C	6100	4005	7100	5605	14	6.02
16	B	6200	3500	7000	2000	7	3.75
18	B	6000	3800	2800	4000	5	4.15

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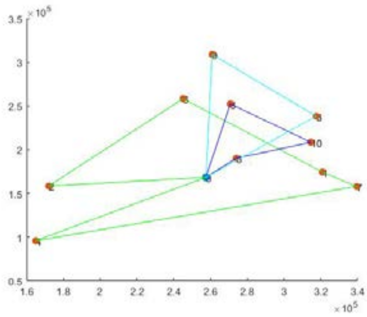

Figure3. dynamic value compensation logistics companies distribution map

Table11 Dynamic value compensation logistics companies distribution table

Vehicle number	Customer ID	Delivery route
1	5	0→6→12→4→15→10→0
2	3	0→17→19→11→0
3	2	0→18→8→0

Comparison of distribution costs:

distribution mode	Regular drivers compensation	Distance costs	Occasional drivers compensation	Total cost
fixed value	1200	25.6	15	1240.6
dynamic value	900	15.1	54.86	969.96

4. Conclusion

In view of the current situation of uneven transportation capacity of logistics distribution, the introduction of crowdsourcing logistics to participate in distribution can solve the above problems to a certain extent. At the same time, it can maximize the utilization of unused resources, further solve the problem of insufficient logistics resources, reduce transportation costs, improve the utilization of resources, and put forward practical solutions for the current distribution problems, And it saves the transportation cost for the enterprise. Different compensation will have different effects. Compared with fixed compensation, dynamic compensation can stimulate the initiative of occasional drivers. Improving the reward rate of occasional drivers can stimulate the enthusiasm of crowdsourcing distribution, relieve the distribution pressure of logistics companies, and reduce the number of vehicles on the road, so as to reduce carbon dioxide emissions, which has a positive impact on the environment. Compared with the fixed rate of return, the dynamic compensation scheme can stimulate the desire of occasional drivers to deliver orders in relatively remote locations, and reduce the situation that no one is willing to deliver orders from long

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distance. This paper only considers a crowdsourcing vehicle with only one order, and does not consider how to obtain the optimal dynamic compensation, which makes this paper have some limitations.

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