The Optimization Model and Application of Crowdsourcing Logistics Distribution Considering the Travel Trajectory of Deliverers

Qiang Wu*, Jun Tu

School of business administration, Liaoning Technical University, Huludao, Liaoning, 125105, China

995250081@qq.com*, tovgar@126.com

Abstract. The problems of supply and demand matching and route planning of crowdsourcing platform are the development difficulties faced by urban distribution O2O platform. This paper stands on the Angle of the platform, considers the actual needs of crowdsourcing distributors and customers at the same time, and introduces the general idea of single-place booking processing time window. Taking into account the customer's expected delivery time window, credibility requirements, the deviation distance limit of crowdsourcing deliverers, the start and end point, the distribution capacity limit system and other factors, without considering the refusal of orders, A multi-objective optimization model is constructed to minimize the total distribution cost, maximize customer satisfaction and minimize the deviation distance of crowdsourcing deliverers. Finally, according to the characteristics of the model, greedy algorithm and genetic algorithm are used to solve it, and the case data of a unit in a city and a district of SF Company is selected for empirical analysis. The results of the study show that the quality of the method is significantly higher than that of the greedy method, the optimization ratio reaches 8.5%, and the benefits of crowdsourcing deliverers, customers and crowdsourcing platforms are maximized.

Keywords: crowdsourcing delivery, supply and demand matching, path planning, genetic algorithms

1 INTRODUCTION

With the development of e-commerce, the logistics distribution industry's demand for couriers has continued to grow rapidly, facing traditional delivery models with the risk of manpower shortages during peak demand periods. To reduce delivery costs for logistics companies and meet the surge in orders during specific times, a crowdsourced delivery model based on the sharing economy concept has been proposed and applied[1]. Studying the crowdsourced delivery problem first requires examining the development status of crowdsourced delivery models both domestically and internationally. As early as 2013, Walmart recruited "part-time couriers" from its consumers to deliver goods for other customers en-route, marking the initial model of crowdsourced delivery[2].

V. Vasilev et al. (eds.), *Proceedings of the 2024 5th International Conference on Management Science and Engineering Management (ICMSEM 2024)*, Advances in Economics, Business and Management Research 306,
https://doi.org/10.2991/978-94-6463-570-6_109

Subsequently, a crowdsourced delivery model adapted to specific regional resident habits and infrastructure was applied, and some foreign scholars have also conducted studies on this. Akeb, by researching residents' daily travel patterns, provided "en-route delivery services" to facilitate last-mile delivery[3]. Previous studies mainly viewed workers as full-time and assigned tasks based on their current locations[4,5]. With the development of the sharing economy and transportation, some individuals with stable jobs are also willing to participate in crowdsourcing as part-time workers; these individuals only accept tasks during commuting or free time, making task assignment based on daily trajectories more meaningful. Moreover, past studies mostly considered the interests of the crowdsourcing platforms and customers, neglecting the interests of crowdsourced delivery personnel, which led to the loss of crowdsourced capacity[6]. Therefore, this paper constructs a multi-objective matching model based on the daily travel trajectories of delivery personnel that maximizes customer satisfaction, minimizes delivery costs, and minimizes the deviation distance for crowdsourced couriers to find a matching scheme that satisfies the interests of all three parties.

2 PROBLEM DESCRIPTION AND MODEL CONSTRUCTION

2.1 Problem Description

Briefly, the problem is described as follows: In a delivery unit, there is a delivery center O, a known set of packages B, and a set of delivery points N. The fixed costs and per distance delivery costs of the couriers are known. From the set of available couriers A, select couriers to deliver the packages, where a courier may deliver multiple packages but must not exceed their delivery capacity, and each package must be delivered by only one courier.

2.2 Model Assumptions and Symbol Descriptions

1）Model assumptions.

①Packages are undifferentiated except for volume;

②Courier delivery tools are not considered, each courier has their own maximum delivery capacity;

③The additional travel distance couriers undertake to complete delivery tasks is within their acceptable range;

④The service time of couriers delivering packages is not considered; arrival at the delivery point signifies task completion.

2）For symbol definitions, see Table 1.

Table 1. Description of symbols

symbols	description	symbols	description
O	Distribution center	d_{ik}^{j}	The distance that distributor j travels from node i to k
A	Parcel collection	d_j	The distance that deliveryman j planned to travel
B	Dispatcher pool	d_{ik}^{j}	The distance that distributor j travels from node i to k
N	Collection of parcel delivery points and distribution centers	d_j	The distance that deliveryman j planned to travel
σ_1	Dispatcher starting point assembly	C_j	Distributor j Unit delivery cost
σ_2	Dispatcher terminal assembly	F_j	Distributor j distributes fixed costs
V	All locations in the transport network	C_j^T	The penalty cost of the delivery agent j for not meeting the expected delivery time of the package
G	A completely directed graph includes a set of points and a set of arcs	x_i^j	Variable 0-1, =1 if package i is delivered by distributor j, otherwise 0
T_{ik}	Time from point i to point K	y_{ik}^{j}	Variable 0-1, =1 if distributor j serves route (i, k) from the starting point, otherwise 0
t_i	The time when the delivery person arrives at point i	a_i^1	Parcel volume
a_i^R	The earliest expected delivery time for parcel i	$a_{i.\min}^2$	Packages require minimum trustworthiness from crowdsourcing deliverers
a_i^L	The latest expected delivery time for package i	b_j^1	Crowdsourced deliverers deliver capacity
ϑ_1	Early to the penalty factor	b_j^2	Crowdsourcing deliverer credibility
ϑ_2	Penalty factor for late arrival	θ_{ij}	Parcel i's satisfaction with deliverer j

2.3 Mathematical Model

$$\max M_1 = \sum_{i=1}^{n}\sum_{j=1}^{m}\theta_{ij}x_i^j \tag{1}$$

$$\min M_2 = \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{m}d_{ik}^jC_jy_{ik}^j + \sum_{i=1}^{n}\sum_{j=1}^{m}F_jx_i^j + \sum_{i=1}^{n}\sum_{j=1}^{m}C_j^Tx_i^j \tag{2}$$

$$\min M_3 = \sum_{i=1}^{n}\sum_{k=1}^{n}\sum_{j=1}^{m}(d_{ik}^j - d_j)y_{ik}^j \tag{3}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{n}d_{ik}^jy_{ik}^j \leqslant d_j\ ,d_j=(b_j^R-b_j^L)\times v\ ,j=1,\cdots,m \tag{4}$$

$$a_i^L \leqslant t_i \leqslant a_i^R \tag{5}$$

$$t_k \geqslant (t_i + T_{ik})y_{ik}^j \tag{6}$$

$$b_j^2x_i^j \geqslant a_{i.\min}^2, j=1,\cdots,m \tag{7}$$

$$\sum_{i=1}^{n}x_i^ja_i^1 \leqslant b_i^1,\ j=1,\cdots,m \tag{8}$$

$$\sum_{j=1}^{m}x_i^j = 1\ ,i=1,\cdots,n \tag{9}$$

$$\sum_{i=1}^{n}x_i^j \geqslant 1\ ,j=1,\cdots,m \tag{10}$$

$$x_i^j\in\{0,1\},\ \ i=\{1,2,\cdots,n\}j=\{1,2,\cdots,m\} \tag{11}$$

$$y_{ik}^j\in\{0,1\},\ \ i、k=\{1,\cdots,n\}\ j=\{1,2,\cdots,m\} \tag{12}$$

$$\theta_{ij}=\begin{cases}1 & b_j^2 \geqslant a_{i.\min}^2\\ 0 & b_j^2 < a_{i.\min}^2\end{cases} \tag{13}$$

$$C_j^T=\begin{cases}\vartheta_1(a_i^L-t_i) & t_i \leqslant a_i^L\\ \vartheta_2(t_i-a_i^R) & t_i \gg a_i^R\\ 0 & t_i\in[a_i^R,a_i^L]\end{cases} \tag{14}$$

Formula (1) represents the overall satisfaction of the parcel party; Formula (2) represents the crowdsourcing delivery cost, which consists of three parts: fixed cost, delivery distance cost and penalty cost of unmet package time window. Formula (3) represents the deviation distance of the crowdsourcing deliverer; Formula (4) indicates that each crowdsourcing deliveryman should meet its driving distance requirements and the formula for calculating the maximum driving distance of the deliveryman; Formula (5) (6) indicates that the arrival time of the crowdsourcing deliverer at the parcel point should meet the requirements of the expected time window of the parcel; Formula (7) represents the credit requirement of the parcel to the crowdsourcing deliverer; Formula (8) represents the capacity requirements of crowdsourcing deliverers; Formula (9) means that each package can only be delivered by one distributor; Formula (10) indicates that all crowdsourcing deliverers participate in the delivery; Formula (11) and (12) represent the range of decision variable values, formula (13) represents the formula for calculating the satisfaction of the parcel, and formula (14) represents the formula for calculating the penalty cost of delivery time.

3 ALGORITHMIC SOLUTIONS

3.1 Proximity Matching Greedy Algorithm

(1) Initialization: Set initial locations of deliverers and initiate empty delivery routes.(2) Distribution center: Use it as the starting point for all deliveries.(3) Select Nearest Parcel: Deliverers pick the closest parcel to their current location repeatedly until all are distributed.(4) Update route: Post-pickup, update the deliverer's location to the parcel's and add the parcel to their route.(5) Calculate cost, offset, and satisfaction(6) End condition:Conclude when all parcels are assigned.(7) Evaluation and output: Compute and output total costs, distances, and satisfaction levels for all routes.

3.2 Genetic Algorithm

The genetic algorithm is suitable for complex optimization and combinatorial optimization problems, characterized by good adaptability and strong search capabilities. Due to its inherent parallelism, it can effectively handle large-scale problems with less time. Although premature convergence can occur, it can be mitigated by controlling initial solutions and incorporating new genetic material. Hence, a genetic algorithm that fits the model characteristics is proposed to solve the crowdsourced matching problem, with specific steps outlined below.

(1)Initialize Population: Generate a set population of individuals, each representing a different delivery scheme.(2)Calculate Fitness: Assess fitness based on total cost, distance, and satisfaction.(3)Selection: Choose individuals for survival based on fitness, typically using roulette wheel selection.(4)Crossover: Pair and recombine selected individuals at a defined crossover rate to produce offspring.(5)Mutation: Introduce mutations in offspring at a set mutation rate to increase genetic diversity.(6)Iteration: Repeat steps until a stop condition or maximum iterations are reached, refining towards an optimal solution.(7)Output Optimal Solution: At conclusion, select the highest fitness individual as the best delivery scheme.

4 CASE STUDY

4.1 Data Sources and Parameter Description

Since the problem studied in this paper is evolved from the actual international business of the express crowdsourcing platform, there is no authoritative literature data to measure the advantages and disadvantages of the algorithm. Therefore, based on the first-hand analysis data of SF's crowdsourcing platform, this paper preprocessed the obtained data to ensure the confidentiality of the company's data. In this paper, the data of parcel and crowdsourcing deliverer information during the order processing period of a unit in a district of Xingcheng City is selected as the analysis sample, and the sample data is shown in Table 2,3.

Table 2. Sample data of crowdsourcing deliverers

Courier_ID	Start.t	End.t	Volume	HistoricalRating	Fixed_Cost	Cost_per_km	Start_Point	End_Point
1	7:38	10:13	1.03	3	11.67	1.48	(0.976, 4.303)	(9.572, 5.983)
2	8:08	10:12	1.14	3.6	25.54	1.47	(2.055 0.897)	(-0.770, 5.610)
3	7:48	9:56	3.93	4.9	21.17	1.53	(-1.526,2.917)	(-7.634, 2.798)
4	7:38	10:29	3.28	3.6	18.48	1.49	(-1.248,7.835)	(-7.132, 8.893)
5	7:16	8:24	0.96	3.8	28.13	1.55	(9.273,-2.331)	(0.436, -1.706)

Table 3. Part of parcel sample data

Package_ID	Volume	MinimumReputation	Pickup_Point	Delivery_Point	Earliest_Delivery	Latest_Delivery
1	0.57	1.3	(0,0)	(-2.140, 6.583)	8:38	10:26
2	0.67	4.5	(0,0)	(1.381, -8.729)	9:08	10:40
3	0.73	3.2	(0,0)	(-9.263, -7.322)	8:48	10:22
4	0.51	1.7	(0,0)	(-9.726, -8.492)	8:38	10:33

1) The average speed of deliverers in this paper is 30km/h.

2) Convert the longitude and latitude of the parcel pick-up point, delivery point and the starting location of the crowdsourcing deliverer into horizontal and vertical coordinates.

3) There are 5 crowdsourcing deliverers, 10 parcels, and the distribution time penalty coefficients are 0.5 and 0.5, respectively. The fixed cost and unit distribution cost of each deliverer are shown in Table 2.

4.2 Example Results Under Different Algorithms

1) Distribution scheme under different algorithms

The distribution schemes of nearby matching greedy algorithm and genetic algorithm are shown in FIG. 1 and FIG. 2 respectively.

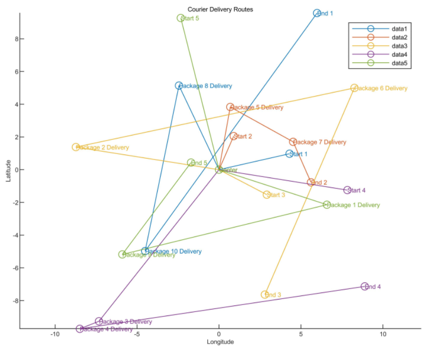

Fig. 1. Nearby greedy matching algorithm allocation scheme

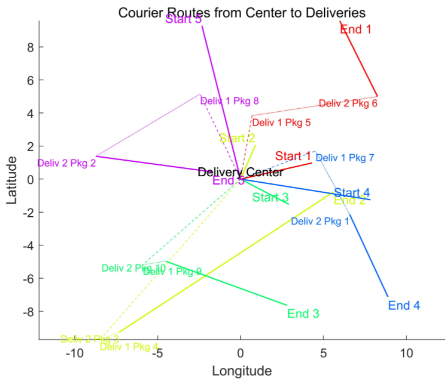

Fig. 2. Genetic algorithm allocation scheme

2) Effect comparison under different algorithms

In the algorithm comparison experiment, the nearest matching greedy algorithm was compared with the genetic algorithm under the crowdsourcing distribution model. Each algorithm repeated the experiment 30 times, and each experiment iterated for 300 times. The algorithm results are shown in Table 4.

Table 4. Comparison of effects of different algorithms

Algorithm	delivery cost/meta	Offset distance /km	Package satisfaction
Nearest matching greedy algorithm	339.9832	107.24	18
Genetic Algorithm	318.78	90.392	17

According to the existing data, the crowd-sourcing matching decision result is solved and the comparative analysis shows that, although the satisfaction of the parcel party in the matching scheme is slightly decreased, the distribution cost and the deviation distance of the crowd-sourcing deliverer are significantly improved, which proves the effectiveness of the model and algorithm in this paper.

4.3 Parameter Sensitivity Analysis

In order to explore the impact of distribution speed on distribution scheme, three distribution speeds of 30, 40 and 50 km/h were set respectively to study their impact on time penalty cost, total distribution cost and customer satisfaction.

Table 5. Results of distribution speed sensitivity analysis

	30km/h			40km/h			50km/h		
	delivery cost/meta	Time penalty cost	Package satisfaction	delivery cost/meta	Time penalty cost	Package satisfaction	delivery cost/meta	Time penalty cost	Package satisfaction
Optimal distribution scheme	318.78	10.85	15	315.40	7.47	16	307.93	0	18

As can be seen from Table 5, when a distributor distributes at a speed of 30, 40, and 50km/h respectively, the number of violations of time window constraints decreases with the increase of the distribution speed, thus reducing the distribution cost of the distribution scheme and improving customer satisfaction

5 CONCLUSIONS

1) Established a crowdsourcing distribution matching model

2) For the multi-objective matching model proposed in this paper, the greedy algorithm and genetic algorithm are used to solve it, and the principle and main steps of the two algorithms are explained.

3) Taking the crowdsourcing platform of SF as an example, a numerical experiment is set to compare the proposed model with the traditional crowdsourcing distribution model. The experimental results show that the proposed model can better save the distribution cost and reduce the deviation distance of crowdsourcing deliverers; The experimental results show that the genetic algorithm is better than other algorithms in terms of optimal solution and running time, which proves the effectiveness of the algorithm.

REFERENCES

1. Wang Y，Zhang D X，Liu Q，et al. Towards enhancing the last-mile delivery: an effective crowd-tasking model with scalable solutions ［J］.Transportation Research Part E:Logistics and Transportation Review，2016，93: 279 － 293.
2. ROUGÈS J F，MONTREUIL B. Crowdsourcing delivery: new interconnected business models to reinvent delivery[C]//. Benoit Montreuil. 1st international physical internet conference. Quebec City, Canada: Physical Internet Initiatives, 2014. p. 1-19.
3. Akeb H，Moncef B，Durand B． Building a collaborative solution in dense urban city set tings to enhance parcel delivery: an effective crowd model in Paris ［J］.Transportation research Part E: Logistics and Transportation review，2018，119: 223 － 233.

4. P. Cheng, L. Chen, and J. Ye, "Cooperation-aware task assignment in spatial crowdsourcing," in 2019 IEEE 35th International Conference on Data Engineering (ICDE). IEEE, 2019, pp. 1442–1453.
5. Y. Zhao, J. Guo, X. Chen, J. Hao, X. Zhou, and K. Zheng, "Coalition based task assignment in spatial crowdsourcing," in 2021 IEEE 37th International Conference on Data Engineering (ICDE). IEEE, 2021,pp. 241–252.
6. X. Bei and S. Zhang, "Algorithms for trip-vehicle assignment in ridesharing," in Thirty-second AAAI conference on artificial intelligence,2018.