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Research on delivery optimization of food delivery orders based on crowdsourcing platform

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Abstract: With the continuous expansion of the food delivery market, the challenges of order allocation and route optimization in crowdsourced delivery have emerged as a critical research focus. While existing studies primarily concentrate on meeting customer demands, improving delivery efficiency, and reducing costs, they often overlook the interests of delivery riders. Addressing this gap, this paper establishes maximum working hours as a constraint for riders while ensuring service quality and maximizing their earnings. A comprehensive weighting system is designed to balance three key factors: delivery time, order deadlines, and rider compensation. The proposed algorithm optimizes routes through a greedy insertion method, aiming to deliver high-quality solutions within riders' available timeframes. Through computational simulations, the study provides actionable recommendations for enhancing order allocation and route optimization in crowdsourced delivery systems.

1. Introduction

In recent years, the food delivery industry has experienced rapid growth with expanding market scale, leading to heightened demands for efficient last-mile delivery. Crowdsourced delivery models under the sharing economy demonstrate significant advantages in optimizing underutilized human resources, enhancing logistics efficiency, and reducing corporate distribution costs. However, this model faces challenges in order allocation and delivery processes, particularly the heavy workloads and unstable income faced by delivery riders in current crowdsourcing systems. Rational order distribution and optimized delivery routes play a vital role in improving rider efficiency, delivering premium services to consumers, and achieving balanced interests among riders, businesses, and customers.

2. Literature Review

Current research on crowdsourced delivery in the food delivery industry primarily focuses on single-level aspects such as order allocation or route optimization. Regarding order allocation, Nan Feiyan [1] proposed a "combine first, then allocate" approach to address uneven order distribution on crowdsourced delivery platforms. Xie Naiming et al. [2] leveraged the cross-supplier order allocation advantages of cloud platforms to develop an integrated scheduling model and establish a cross-supplier order allocation framework. Yang Donglin et al. [3] constructed a tabu search algorithm to simulate centralized order allocation methods for Cainiao Network's last-mile delivery challenges. Zhang Qi [4] adopted a rolling time-domain method to transform dynamic order allocation into multiple static problems by fully considering rider experience. Bian Zhe [5] implemented an improved K-means algorithm for order clustering analysis, assigning clustered orders to suitable delivery personnel.

In vehicle delivery path optimization, Jiang Li et al. [6] developed a time-windowed vehicle routing model to address issues like empty runs and redundant deliveries in crowdsourced logistics, minimizing both time penalty costs and transportation expenses. Li Xiaoman [7] proposed three open-source delivery path optimization models for O2O food delivery under crowdsourcing frameworks. Chen Luqian[8] designed the TS-Ropt online algorithm to solve real-time pickup-and-delivery problems for food orders with dynamic order generation, considering their instant arrival characteristics. Li Hongmei [9] formulated DTR (Dynamic Time-Restriction) and DRR (Dynamic Resource-Restriction) strategies to resolve multi-pickup point dynamic delivery challenges under different incentive mechanisms, addressing the mismatch between standardized instant delivery services and clients' varying urgency requirements.

Current literature reveals that the predominant approach in end-to-end crowdsourced delivery order allocation involves clustering orders and centrally assigning them to riders based on geographic and temporal zones, with priority-based distribution to different couriers. Regarding route optimization, research has evolved from static delivery path analysis to time window-based strategies. Modern methods now incorporate dynamic order and courier considerations, establishing incentive mechanisms as constraint conditions for route optimization. This progression reflects a gradual transition from standardized to customized delivery systems.

3. Problem Description

With the continuous development of the crowdsourcing delivery model, the scale of food delivery riders has expanded significantly, market competition has intensified, and order unit prices (including per-kilometer delivery costs) have shown a sustained downward trend. In some scenarios, the per-kilometer price has dropped below 1 yuan, severely compressing riders 'profit margins. Under these circumstances, platform order allocation must balance the interests of riders, merchants, and consumers. While ensuring service quality through fixed time window fulfillment, it should prioritize maximizing riders' earnings as the core selection criterion. The study constructs a comprehensive weighted index system by analyzing three key factors: delivery distance (convertible to delivery time), latest delivery time, and order profitability. Orders meeting time constraints are included in the allocation scope, while unaccepted orders enter the next round of dynamic allocation, with delivery routes being updated simultaneously.

Given that delivery riders may receive new potential orders during their delivery process, the order allocation and route optimization must be designed in tandem. During the order screening phase, a comprehensive weighting system is established based on time constraints, delivery distance (including delivery time), and order profitability to determine the priority of preprocessed orders. In the route optimization phase, a greedy algorithm is employed to generate an initial delivery route under the assumption of uniform delivery speed and the mutual convertibility of distance and time. Subsequently, a dual-constraint verification process is conducted (ensuring each delivery point's arrival time meets the platform's time window requirements and the total delivery time does not exceed the rider's working hour limit) to ultimately determine the optimal delivery route for this phase.

Problem hypothesis:

(1) Since the problem considers the rider's choice of order and service order when receiving the order, the position of each order, the relative position of the rider and the order, the latest arrival time stipulated by the platform, and the revenue of each order are all known.

(2) Every rider aims to maximize the daily revenue and ensure that the order is delivered within the time limit specified by the platform.

(3) The running speed of the rider is a fixed speed, without considering the influence of weather conditions and traffic conditions.

4. Model Establishment

To simplify the problem, we define $(o, 2n+1)$as the origin;

$V=P\cup D\cup\{0,2n+1\}$: represents the set of all pickup P and delivery points D;

$B_{ik}k$: indicates when the vehicle k $(k\in K)$starts service at the location $i(i\in V)$;

$Q_{ik}ki$: represents the load carried by the vehicle when it leaves the position;

$S_i i$: indicates the time the rider is in the location service;

$t_{ij}ij$: represents the time it takes for the rider to traverse from one location to another;

Cap: represents the maximum cargo capacity of each vehicle.

At the pickup point we assume $q_p>0q_p=-q_p$the demand, and at the corresponding delivery point, the demand is.

$$\text{minimize}\sum_{i\in V}\sum_{J\in V}\sum_{k\in K}c_{ij}x_{ijk} \tag{1}$$

$$\sum_{k\in K}\sum_{j\in V}x_{ijk}=1,\forall i\in P \tag{2}$$

$$\sum_{j\in V}x_{ijk}-\sum_{j\in V}x_{(n+i)jk}=0,\forall i\in P,k\in K \tag{3}$$

$$\sum_{j\in V}x_{ijk}-\sum_{j\in V}x_{ijk}=0,\forall i\in P\cup D,k\in K \tag{4}$$

$$\sum_{j\in V}x_{ojk}=1,\forall i\in K \tag{5}$$

$$\sum_{i\in V}X_{i(2n+)jk}=1,\forall i\in K \tag{6}$$

$$B_{jk}\geq B_{ik}+t_{ij}+s_i-M(1-x_{ijk}),\ \forall i,j\in V,k\in K \tag{7}$$

$$Q_{jk}\geq Q_{ik}+q_j-M(1-x_{ijk}),\forall i,j\in V,k\in K \tag{8}$$

$$B_{(n+i)k}\geq B_{ik}+t_{i(n+i)}+s_i,\forall i,j\in V,k\in K \tag{9}$$

$$e_i\leq B_{ik}\leq l_i,\ \forall i\in V,k\in K \tag{10}$$

$$\max\{0,q_i\}\leq Q_{ik}\leq\min\{Cap,Cap+q_i\},\ \forall i\in V,k\in K \tag{11}$$

$$x_{ijk}\in\{0,1\},\ \forall i,j\in V,k\in K \tag{12}$$

(Equation1) is the objective function of minimizing the total distribution distance;

(Equation 2) Ensure that all nodes, such as pickup points and delivery points, are accessed only once;

(Equation 3) ensures the matching condition, that is, the same pickup point and delivery point corresponding to the same demand must be served by the same rider;

(Equation 4) ensures that vehicle k will depart from node i upon arrival.

(Equation 5) and (Equation 6) indicate that all vehicles must leave the origin and eventually return to the origin;

(Equations7) and (Equations8) represent time and demand constraints respectively, where M denotes a very large number.

(Equation 9) ensures that the pickup point must be before the delivery point;

(Equation 10) indicates that the vehicle must strictly serve each node within the time window;

(Equation 11) represents the total capacity constraint of the vehicle;

(Equation 12) represents the range of x values.

This study decomposes the crowdsourced delivery problem into task assignment and route optimization, achieving maximum rider revenue through joint optimization of both. For each generated assignment plan, vehicle routes are optimized using cost as the selection criterion until the optimal solution is obtained. The greedy insertion algorithm is employed, with its core principle being: starting from the initial point, sequentially selecting the nearest unvisited location to insert into the current path until full coverage is achieved. The basic steps are:

1) Select a starting point on the current path.

2) Select the nearest unvisited location to the current path and insert it to minimize the total path length. The insertion method can be performed at any point along the path to achieve this goal.

3) Mark the selected locations and update the current path.

4) Repeat steps 2 and 3 until you have visited all the locations.

5) Connect the last location to the starting location to form a closed path.

5. Path optimization analysis based on delivery platform scenario simulation

Building upon the multi-stage decision-making model and greedy insertion algorithm for potential orders developed earlier, this section conducts a scenario-based simulation analysis. Through solving the rider's problem, we validate the model's rationality and effectiveness while proposing efficient delivery strategies for order allocation and route optimization in food delivery services.

5.1 Scenario Simulation

(1) Order data

Consider a scenario where a rider (A) handles five potential orders (a, b, c, d, e). Each order has a fixed unit price (R), with the platform setting a time limit (T) (Table 1) and delivery time (t) between each pickup point (Table 2). The T_{max}=4rider operates on a daily part-time schedule, with a maximum working hour limit. The delivery time is calculated by dividing the distance between orders by the rider's fixed speed.

Table 1 Unit price per order and limited time

time quantum	**Stage 1**			**Stage 2**	
order for goods	a	b	c	d	e
Unit price (RMB)	5	6	10	3	5.5
Time limit T (hours)	4.5	5	3.5	4.5	3

Table 2 Delivery time matrix for each order (unit: hours)

Delivery time	**o**	**a**	**b**	**c**	**d**	**e**
o	0	1.5	1.2	2	0.5	1.5
a	1.5	0	1.5	2	0.5	0.7
b	1.2	1.5	0	0.8	1	1.2
c	2	2	0.8	0	1.5	0.8
d	0.5	0.5	1	1.5	0	1
e	1.5	0.7	1.2	0.8	1	0

(2) Combined Weight

Based on the limited time, delivery time and unit price of each order, the three factors are classified and synthesized to obtain the comprehensive weight W.

The more flexible the platform's delivery time limits (maximum delivery time) are, the more room it leaves for the system to optimize order allocation, which helps reduce delivery costs. Higher order prices mean greater earnings for riders, while shorter delivery times allow faster order completion.

The above three factors, the longer the time limit, the higher the unit price of the order, and the shorter the time for the rider to complete the delivery of the order, the greater the revenue value, that is, the greater the proportion of the comprehensive weight W.

The platform's time limit and order unit price have a positive correlation with the comprehensive weight, while the delivery time has a negative "correlation.The comprehensive weight calculation is as follows"

The comprehensive weight W= (specified time * unit price) / delivery time

Each order is compared with comprehensive weights, and the orders are accepted in order of weight. The priority of the orders to be preprocessed is determined according to the weights.

There are three potential orders a, b, and c. The comprehensive weights of the three points at the original location are calculated. The first stage of order receiving is the process of the rider receiving and processing the order at the distribution center o.

Using the formulaW_{oa}, W_{ob}, W_{oc}, we calculate the comprehensive weights between o and a, b, c, and determine the delivery times for a, b, c in the first stage. Based on the known delivery time matrix, we obtain t_{oa}, t_{ob}, t_{oc}, as shown in Table 3.

Table 3 Weight Calculation

order for goods	**unit-price (Yuan)**	**qualification time (hour)**	**Delivery time (hour)**	**W**
a	5	4.5	1.5	W_{oa}=4.5*5/1.5=15
b	6	5	1.2	W_{ob}=5*6/1.2=25
c	10	3.5	2	W_{oc}=3.5*10/2=17.5

Therefore W_{oa}=15, W_{ob}=25, W_{oc}=17.5, $W_{ob} > W_{oc} > W_{oa}$, the three potential orders are preprocessed in the order of b, c, and a.

5.2 Path Optimization

After the pre-processing of potential orders, the path arrangement of each stage is obtained by comprehensively considering the constraints such as the limited time of the platform order and the maximum working time per day.

Assuming the second stage follows immediately after the first order is completed, mark the completed order and update the path optimization scheme again.

The first stage of order delivery is shown in Table 4:

Table 4 Problem solving process 1

step	Order delivery and calculation phase 1		
Weight comparison	$W_{ob} > W_{oc} > W_{oa}$		
Status update	Order B preprocessing	Add order c	Add to order
Compare delivery times (Greedy Insertion Method)	t_{ob}	$t_{ob}<t_{oc}$	$t_{ob}<t_{oa}<t_{oc}$ $t_{bc}<t_{ba}$
Initial path	$o \to$b	$o \to b \to$c	$o \to b \to$c$\to$a
Is the delivery node Set a time limit	$t_{ob} \le T_{ob}$	$t_{ob}+t_{bc} \le T_{oc}$	$t_{ob}+t_{bc} \le T_{oc}$ $t_{ob}+t_{bc}+t_{ca} \le T_{oa}$
Is it a rider? Service hours	$t_{ob} \le T_{max}$	$t_{ob}+t_{bc} \le T_{max}$	$t_{ob}+t_{bc}+t_{ca} \le T_{max}$
Final path	$o \to b$	$o \to$b$\to$c	$o \to b \to$c$\to$a

The greedy insertion method is used to sort and obtain the initial path as shown in Figure 1:

Figure 1 First stage of path optimization: Greedy insertion method

The final path is obtained by continuously adjusting the path optimization scheme based on the two constraints of time limit and total working time of riders. The process is as follows:

(1) The first is order b, t_{ob}=1.2<Tob=5, $o \rightarrow b$ is the initial path being;

(2) Next, add order c. After comparison, the updated path satisfies the constraint conditions. t_{ob}=1.2<t_{oc}=2t_{ob}+t_{bc}=1.2+0.8=2≤T_{oc}=3.5, $o \rightarrow b \rightarrow c$is the initial path being.

(3) Finally, add order a and compare it with tob and toc.

because : t_{ob}=1.2<t_{oa}=1.5<t_{oc}=2t_{bc}=0.8<t_{ba}=1.5

So the initial path is: $o \rightarrow b \rightarrow c \rightarrow a$

And the relationship between the delivery time of each order and the limited time, reach : $t_{ob}+t_{bc}=1.2+0.8=2 \leq T_{oc}=3.5$

$$t_{ob}+t_{bc}+t_{ca}=1.2+0.8+2=4 \leq T_{oa}=4.5$$

also because :

The total working time of the first phase is:

$$t_{ob}+t_{bc}+t_{ca}=1.2+0.8+2=4 \leq T_{max}=4$$

Do not exceed the rider's part-time work hours limit.

If the path optimization scheme satisfies the above two constraints, the final path of the first stage is determined as: $o \rightarrow b \rightarrow c \rightarrow a$

The second phase is defined as follows: After the rider completes the first order (i.e., order e), the system updates the route plan. During this phase, new potential orders d and e become available. Since the rider accepts and processes orders during the completion of the first order, the solution approach is illustrated in Table 5.

Table 5 Problem solving process 2

step	**Order delivery and calculation phase 2**	
Weight comparison	W_{be}> W_{bd}	
Status update	Add order	Add order d
Compare delivery times	$t_{bc}<t_{be}<t_{ba}$ $t_{ce}<t_{ca}$	$t_{bc}<t_{bd}<t_{be}<t_{ba}$ $t_{ce}<t_{cd}<t_{ca}$, $t_{ea}<t_{ed}$
Initial path (Greedy Insertion Method)	$o \rightarrow b \rightarrow c \rightarrow e \rightarrow a$	$o \rightarrow b \rightarrow e \rightarrow c \rightarrow d \rightarrow a$
Whether the received order is Set a time limit	$t_{bc}+t_{ce} \leq T_{be}$ $t_{bc}+t_{ce}+t_{ea} \leq T_{oa}-t_{ob}$	$t_{bc}+t_{ce}+t_{ea}+t_{ad} \leq T_{bd}$
Is it a rider? Service hours	$t_{ob}+t_{bc}+t_{ce}+t_{ea} \leq T_{max}$	$t_{ob}+t_{bc}+t_{ce}+t_{ea}+t_{ad}<T_{max}$
Final path	$o \rightarrow b \rightarrow c \rightarrow e \rightarrow a$	$o \rightarrow b \rightarrow c \rightarrow e \rightarrow a \rightarrow d$

With two potential orders (d and e), calculate the comprehensive weight from the current position W_{bd}=13.5, W_{be}=13.75 W_{be}> $W_{bd}$to each point. As shown in Table 6, the result is obtained.

Therefore, the two potential orders are preprocessed in the order of e and d.

Table 6 Weight Calculation

order for goods	**unit-price (Yuan)**	**qualification time (hour)**	**Delivery time (hour)**	**W**
d	3	4.5	1	W_{bd}=4.5*3/1=13.5
e	5.5	3	1.2	W_{be}=3*5.5/1.2=13.75

After entering the scope of preprocessing, the greedy insertion method is used for sorting. The initial path is shown in Figure 2.

First, for the e-order, we need to sequentially compare the delivery times between e, a, and c with the current consumer b.

because, t_{bc}=0.8<t_{be}=1.2<t_{ba}=1.5, t_{ce}=0.8<t_{ca}=2

So the initial path is: $o \to b \to c \to e \to a$

And: $t_{bc}+t_{ce}=0.8+0.8=1.6 \leq T_{be}=3$

$$t_{bc}+t_{ce}+t_{ea}=0.8+0.8+0.7=2.3 \leq T_{oa}-t_{ob}=4.5-1.2=3.3$$

Path confirmation: $o \to b \to c \to e \to a$

When adding order d, we must sequentially compare the delivery times of a, c, and d with those of current consumer e.

reach : $t_{bc}=0.8<t_{bd}=1<t_{be}=1.2<t_{ba}=1.5$

$$t_{ce}=0.8<t_{cd}=1.5<t_{ca}=2,\ t_{ea}=0.7<t_{ed}=1$$

The initial path is: $o \to b \to c \to e \to a \to d$

also because: $t_{bc}+t_{ce}+t_{ea}+t_{ad}=0.8+0.8+0.7+0.5=2.8 \leq T_{bd}=4.5$

Total working hours:

$$t_{ob}+t_{bc}+t_{ce}+t_{ea}+t_{ad}=1.2+0.8+0.8+0.7+0.5=4 \leq Tmax=4$$

The rider's working hours are met, so the final path of the second stage is updated as: $o \to b \to c \to e \to a \to d$

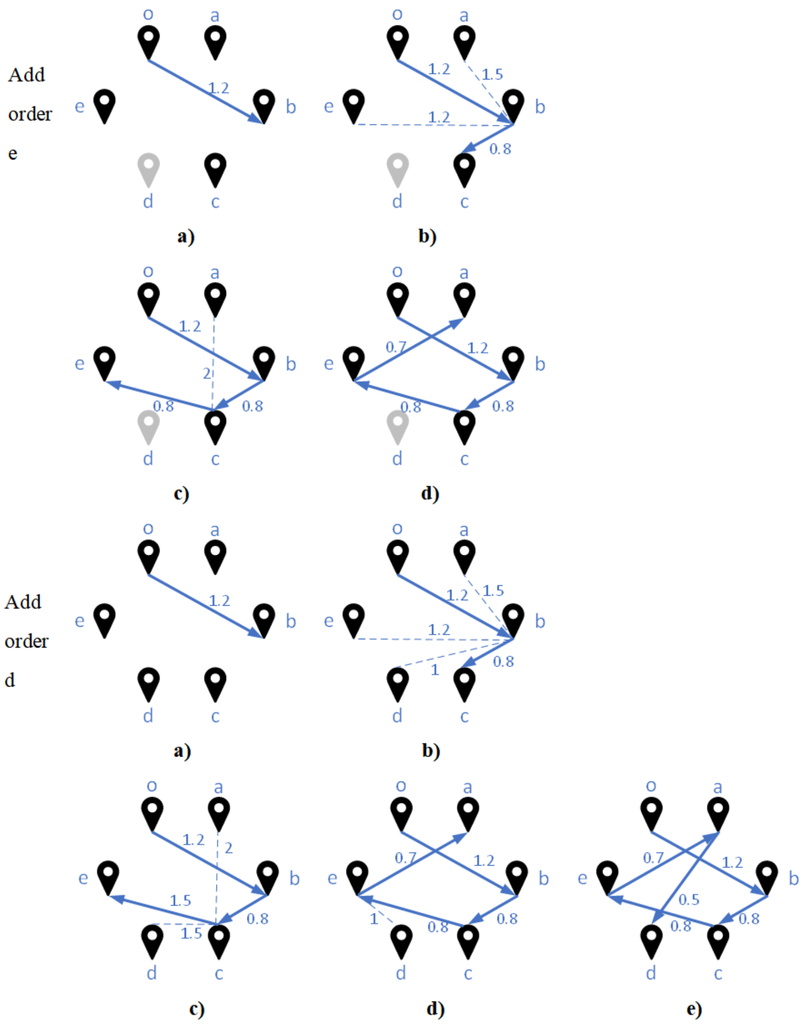

Figure 2 Path optimization stage 2-Greedy insertion method

5.3 Result Analysis

The data above is optimized by considering the three factors of the limited time, delivery time and unit price of the order stipulated by the platform, and using the greedy insertion method to improve the order allocation and path optimization, so as to maximize the rider's income.

The analysis of profit maximization can be analyzed from three aspects:

(1) Analysis of order punctuality rate and delivery efficiency

By implementing order allocation and route optimization strategies, every accepted order is delivered within the stipulated timeframe, ensuring both punctuality and delivery efficiency. On Meituan's platform, riders are rated based on their service quality and delivery performance. Those with higher ratings gain a clear advantage in both order volume and earnings.

(2) Analysis of penalty deductions for platform order timeouts

In recent years, the platform has been increasing the penalty scale for order timeout. At present, the penalty scale for order delay is as follows:

If the order expires (0,6) minutes, 40% of the order income will be deducted.

If the order exceeds the [6,12) minute limit, 50% of the order income will be deducted.

If the order exceeds the [12,18) minute limit, 60% of the order income will be deducted.

If the order exceeds the time limit (18,∞) minutes, 70% of the order income will be deducted.

Delivery within a limited time can not only improve the rider's reputation, but also avoid the deduction of fees by the platform due to delivery delay, which will affect the overall revenue of the order.

(3) Analysis of order revenue indicators

Both the order quantity and the revenue per order can directly affect the order revenue of the rider during the whole delivery process. Within the working time of the rider, ensure the maximum order quantity and the highest unit price of the order. The sum of the unit price of each order can intuitively see the maximization of the total revenue.

Now the path is optimized under different constraints, and the final path under the consideration of comprehensive weight and path optimization is analyzed separately, and the results presented by the order quantity and revenue value are compared.

When neither order allocation through comprehensive weighting metrics nor greedy insertion method is employed for path optimization, the system assumes that orders are sorted based on their delivery time metrics from stage location to destination. Subsequent orders are sequentially inserted and processed according to the sequence of the previous stage.

Table 7 Result Analysis

Order selection policy	**Final path**	**net cycle time (h)**	**Orders received (individual)**	**total revenue (Yuan)**
No comprehensive weight indicator (no path optimization)	$o \to b \to a \to d$	3.2	3	14
Comprehensive Weighting Indicator (No Path Optimization)	$o \to b \to c \to a$	4	3	21
No comprehensive weight indicator (path optimization)	$o \to b \to c \to d \to a$	4	4	24
Comprehensive Weighting Indicator (Path Optimization)	$o \to b \to c \to e \to a \to d$	4	5	29.5

As shown in Table 7, the introduction of comprehensive weighting metrics and the greedy insertion method has significantly enhanced order allocation and path optimization. The increased order volume and improved overall efficiency clearly demonstrate how this algorithm plays a pivotal role in boosting riders' order acceptance efficiency, service quality, and revenue generation.

6. Conclusion

This study focuses on practical applications of food delivery crowdsourcing, integrating industry trends and prior research findings. From the rider's perspective, it addresses order allocation and route selection challenges to maximize earnings. The research comprehensively evaluates core factors including delivery distance, time, and order revenue, introducing a comprehensive weighting evaluation system. By applying the greedy insertion method from the greedy algorithm, the study validates the solution's rational effectiveness through simulated scenarios and computational examples.

The main work and achievements are as follows:

(1) Based on the actual operation of crowdsourcing real-time delivery, and considering the key parameters such as the location of demand points, delivery distance, time and income, a comprehensive research and analysis is carried out by constructing heuristic algorithm and order allocation strategy.

(2) Based on the realistic setting of the delivery point, workload, vehicle speed limit, maximum cargo capacity and other assumptions, it provides reference ideas for the platform decision.

(3) The research verifies the effectiveness of the selected method, which not only provides a new perspective for balancing the interests of the platform, merchants and riders and promoting the sustainable development of the industry, but also has important social significance by paying attention to the rights and interests of riders and creating a fair competition environment.

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