Research on Mathematical Model of Balancing the Interests of All Parties in Food Delivery

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Abstract. In this paper, we study the delivery order pattern of take-out riders in Chinese society, adopt a time window function to give a reward and punishment measure for the complete quality of riders under various factors, and adopt hierarchical analysis to obtain and quantify the degree of influence of different factors on delivery, and get the commission scheme design so that the riders can get the maximum commission. Then, from the perspective of game theory, we establish a two-stage game model under the non-cooperative game, with the first stage of the game being the takeaway demand realizer and the second stage of the game being the takeaway demander and the contacting platform, and finally select a win-win solution with a balanced game. Finally, the pricing model proposed in the previous paper is optimized iteratively, considering the addition of long-distance as well as cross-regional distance quantification factors, and considering the case of dedicated personnel working exclusively. This paper proposes an equilibrium state for the four ends of the platform, merchants, consumers, and riders, and proposes a cross-regional and long-distance delivery scheme with certain feasibility, giving the platform and riders the possibility to expand the sales area and delivery area.

Keywords: Time window; Hierarchical analysis; Two-stage game model; Pricing model.

1. Introduction

With the current social progress, the delivery business has become an important part of people's lives, and the delivery business has promoted the rapid development of the catering industry and the career of delivery riders, but the current rapid development of society, the delivery behavior of delivery riders under the monitoring of the platform, driven by the analysis of delivery data, the platform set delivery order time for riders constantly reduced, resulting in the current delivery riders exist There is a large gap between the cost of labor and the cost of the return, and the behavior of delivery riders is gradually becoming cheaper, and gradually detracting from the current social development goal of building a well-off society.

Catering O2O industry refers to the use of the Internet to divert online users offline to bring customers to caterers and increase revenue; or to divert offline customers to online for maintenance or customer relationship management, to extend the consumption cycle of customers and increase the number of customers' consumption. Catering O2O is a huge branch inside the O2O industry. It includes both Internet companies providing Internet-enabled applications for catering companies and catering companies actively embracing the Internet.

In the face of the epidemic, catering has shown a stronger risk resistance. In particular, catering online orders showed a strong rebound trend. Meituan data showed that the overall online orders of catering in February 2020 dropped 91.6% compared with the same period of the previous year; the overall online orders in March dropped 59.8% year-on-year; the overall online orders in April started to recover rapidly, and the growth rate turned positive for the first time in May, and has been climbing since then, and achieved year-on-year growth of 107.9% in December.

According to Cato data, China's O2O market has been growing rapidly in recent years, and in 2020, the O2O market size reached 263 million yuan. Combined with the share of in-home O2O catering and in-store O2O catering from Meituan data, China's catering O2O market scale is close to 187 million yuan in 2020. This accounts for 71.2% of the overall O2O market scale. The penetration rate of China's catering industry O2O penetration rate has been soaring. 2020 benefited from the impact of the new crown epidemic, the penetration rate of catering O2O in the whole catering industry market scale accelerated to 47.37%. O2O takeaway is the largest market segment in China's catering O2O industry. According to CNNIC data, as of December 2020, the scale of online takeaway users in China reached 419 million, up 21.03 million from March 2020, accounting for 42.3% of the overall Internet users.

The above data proves that the takeaway industry has become the mainstream trend under the epidemic, and in the current study, there is countless "last mile" for the takeaway industry, but in many cases in real life, the "last mile" appears to be a bit idealized, this paper will study the takeaway delivery solution model that exceeds one kilometer, longer distance and cross-regional, and give some reasonable order delivery commission pricing strategy for merchants and platforms for reference.

To sum up, to help riders get out of the involution crisis under the current algorithmic crushing behavior of big data and to amend the current model of intelligent optimization algorithm, this paper analyzes the content of rider delivery orders, studies the different situations of rider delivery of delivery orders and the pain point problems under the current society, analyzes and helps the circulation of items from consumers' demand for delivery to rider delivery orders to consumers' hands, improves rider In the current context of the delivery commission situation, improve the happiness of riders in the current take-out closed-loop, enhance the consumer's view of consumption, satisfaction, promote the economic interests between the platform and merchants to establish a highly generalizable, practical and a reference value of the take-out delivery pricing model and a multi-body game balance approach.

2. Related Work

In the cross-regional and long-distance distribution, previous authors did this:

Jia Xiaoyan [1] in the study of dangerous goods transportation and distribution according to the distance and transportation coverage area, divided into two kinds of long-distance intercity transportation between production and marketing locations across regions and short-distance distribution on urban road networks.

Xiao Zhengzhong, Tan Jian, Zhou Yufeng, Zeng Jun [2] assembled a genetic algorithm and ant colony algorithm to solve the optimal scheduling scheme for cross-regional distribution, including vehicle scheduling and selection, customer assignment method, route optimization, etc.

Liu Dengtong, Yi Jianqiang, and Tan Min [3] applied the segment switching factor fuzzy control method to the long-distance crane transportation system.

Gao Xinhui [4] used fuzzy time and quantitative grading fresh fruit maturity methods to model the cross-regional fresh fruit distribution path considering the maturity change and some uncertain time occurrence in the transportation process.

Liangran Wu, Jian Lin, Yi-Chi Liu, and Min Liu [5] proposed a collaborative inter-regional distribution method based on vehicle distribution routes for the problems of unreasonable vehicle path planning and low loading rate in large-scale multi-regional logistics distribution of single logistics centers. The method generates a regional cooperative distribution network through the topological relationship between distribution regions, then generates the initial distribution routes of vehicles based on the information of the available cargo regions in one distribution, and adjusts the distribution routes among the routes with adjacent relationships, to form the final distribution routes of vehicle path distribution regions.

Wu Shujuan [6] incorporated the idea of saving heuristic algorithm based on genetic algorithm in the vehicle route optimization problem to construct a new algorithm ----- genetic saving hybrid algorithm, which makes the route optimization capability, operation efficiency, and reliability all improve to some extent.

In the study of offline delivery in O2O mode, Li Jinghong [7] focused on "order allocation" and "path optimization", and proposed a new order allocation algorithm for the order allocation problem and a genetic algorithm-based path optimization algorithm for the path optimization problem, which made the convergence of the algorithm faster and more efficient.

Ye Lan [8] combined the characteristics of the tobacco monopoly and proposed a new method of cross-regional distribution route optimization for existing cigarette distribution routes from the perspective of customer demand by using a coverage model.

Ge Xianlong, Huang Yu, and Tan Baichuan [9] proposed a multi-stage joint cross-regional distribution strategy for the real problems in urban logistics distribution under traffic restriction conditions. The optimization objective of minimizing the sum of the variable cost of fuel consumption and fixed cost of vehicle start-up is designed to establish a multi-stage inter-regional joint distribution model for traffic restriction, which fully considers various factors such as distribution distance, on-board rate, and driving speed.

G Guo, S Guo, X Wang [10] constructed a two-stage cross-regional closed-loop logistics network and distribution vehicle path optimization model for fresh e-commerce enterprises under a carbon trading environment for the problem of cross-regional closed-loop logistics network and path planning of fresh e-commerce enterprises under carbon trading.

G Sun, Z Tian, R Liu, Y Jing, Y Ma [11] solved the take-out route delivery problem (TRDP) with order allocation and unilateral soft time window constraints mainly from the perspective of scheduling efficiency as well as genetic algorithm, which provided some solution ideas for cross-regional delivery.

Y Qiu, M Shi, X Zhao, Y Jing [12] constructed a three-party evolutionary game (ETG) model and a system dynamics (SD) model with higher-level emergency management (HAE), LAE, and ELE as the main stakeholders. The core idea of the model is how to make all stakeholders finally reach the (1, 1, 1) equilibrium, which provides some ideas on how to complete the cross-regional delivery of take-out more efficiently.

When Yan Liu et al [13] [14] conducted the optimization of the food delivery network, they proposed the use of spatial crowdsourcing to construct a food network, in which food delivery in the food network is more sensitive to time demand. Considering the O-OTOD aspect (food delivery by cabs incidental to carrying passengers) and the D-OTOD aspect (cabs exclusively deliver food without carrying passengers), a two-stage approach is proposed, including a construction algorithm and an adaptive large neighborhood search (ALNS) algorithm based on simulated annealing.

3. Methods

3.1 Rider's time-out program design

Studying the delivery situation of take-out riders, it is analyzed that the current problem belongs to the planning problem under the consideration of the rider's riding safety perspective and high-quality completion of the order service, so for the current design situation of the rider's delivery time, it can be split into three major modules: delivery time t(s), loss time t(e), and pickup time t(q).

1) For the delivery time t(s), analyzing the current status of take-out delivery [15][16], the route has been optimized in the app used by the rider, so this paper does not consider the choice on the route and uses the parameter t(s), using the total distance divided by the average speed (S/V).

2) For the loss time t(e), since the analysis results in the total delivery arrival time, the loss time already includes the time lost due to traffic light waiting time, yielding to pedestrians, road congestion, etc.

3) For the pickup time t(q), there are two cases as follows:

a) The rider spends a certain amount of time to reach the store, at which time the store has already served the meal both the pickup time is the time spent by the rider to the store $t(q_r)$.

b) The rider takes a certain time to arrive at the store, at which time the store is not yet out, and needs to wait, both the rider pickup time for the store meal time $t(q_k)$, where the merchant meal time prediction model [19] is

$$t(q_k) = \theta_{id} \cdot d_n \cdot N \cdot \sigma_t \cdot \omega_d \tag{1}$$

Then the pick-up time is

$$t(q) = \max\big(t(q_r), t(q_k)\big) \tag{2}$$

3.2 Multiple linear regression equation about time

This question uses hierarchical analysis [20] to calculate the weights of the internal and external influences on the total rider satisfaction, and then after this calculation, the weight values are linearly combined with each influencing factor to obtain the equation about time, and to get the optimal solution value, the dynamic commission pricing is obtained by multiple linear regression equation.

1) Establishing a progressive hierarchy of total rider satisfaction

The 6 factors of total rider satisfaction were stratified into a target level of "total rider satisfaction", a criterion level of "internal influences" and "external influences", and a solution level of the target layer is "rider satisfaction", the criteria layer is "internal influence" and "external influence", and the solution layer is 6 factors. The figure below shows:

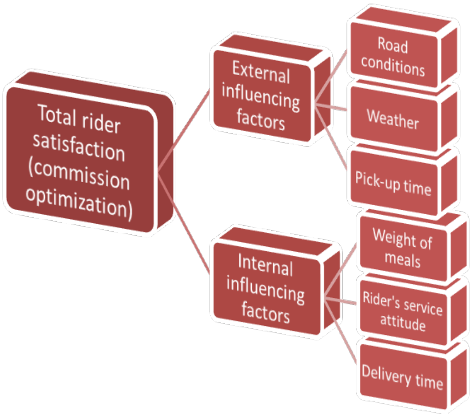

Fig. 1 Hierarchy of factors for total rider satisfaction

2) Build a two-by-two comparison discriminant matrix

The influence of the criterion level on the program level is analyzed here, and since the criterion level is divided into internal and external influences, the discriminant matrix for the two-comparison is also divided into two matrices to be created. The ratio of the influence of X_i and X_j on the upper-level objectives is represented by a_{ij}. The following table shows:

Table 1. Relative importance of a_{ij} taking values

Relative importance: a_{ij}	definitions
1/3, 1/2	Distribution time in the inverse ideal state of the relationship between X_i and X_j corresponding to the above levels
1	If equivalent to: Assignment 1
2	If X_i is a little more important than X_j: Assign 2
3	If X_i is more important than X_j: Assign 2

This yields the positive reciprocal inverse matrix:

$$\begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \tag{3}$$

And the consistency index CI, for which the solution formula is:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{4}$$

The average of the CI of a series of positive and negative matrices is used as the random consistency index RI.

The consistency ratio CR is calculated using the consistency index CI and the random consistency index RI:

$$CR = \frac{CI}{RI} \tag{5}$$

If CR < 0.1, the consistency of the discriminant matrix is considered acceptable, otherwise the consistency of the discriminant matrix is considered unacceptable and the discriminant matrix should be modified.

3.3 Two-stage game model

A feasible win-win solution is now proposed to establish a two-stage game model [22] [23] [24]: so that the whole system is divided into two parts, one occurring between the delivery platform, the rider, and the merchant, and the other occurring between the delivery platform and the customer, and its Nash equilibrium solution is explored separately.

The three-way model is first constructed, and its corresponding diagram is shown below:

Table 2. Brief description of the tripartite model

Symbols	Symbol Description
R_1	Platform policy favors riders
R_2	Platform policies favor lower merchants
U_1	Takeaway platforms offer concessions
U_2	Takeaway platforms do not offer activities
P_1	Merchants choose the merchant independent delivery brought revenue
P_2	The benefits of merchants choosing platform riders for delivery
H_1	Riders are willing to work overtime
H_2	Riders are normally off work
M_1	Revenue generated by customers choosing merchants' self-delivery stores to place orders
M_2	Revenue generated by customers choosing platform riders for delivery

According to the previous analysis, it can be seen that in the whole process of take-out orders, the four parties are platform, merchant, rider, and consumer, so according to the game theory, we explore the win-win way of each subject for order delivery and establish a two-stage game model under the non-cooperative game to analyze the game situation.

3.4 Cross-regional, long-distance distribution

Take the range of common electric vehicles in the market L = 50km.

Considering the number of daily orders completed by the rider, the order delivery distance is extended to 1/5 of the maximum range based on 3 km, which is 10 km. At this point, the increase in the maximum order distance makes the impact of the factors in the model of problem 3 amplified, and the increase in the distance has a direct impact on the delivery cost of a single order, which leads to an increase in the commission $f(x)$ in the multiple linear regression model, and the parameter k is set as a coefficient to measure the degree of increase, which is related to the increased distance, to obtain a new objective function $F(x) = kf(x)$. For cross-regional orders, the case under the consideration of dedicated work [25] [26] is used, and the cross-regional orders are delivered by crowdsourced riders. In general, cross-regional orders are delivered over large distances, and the commission scheme uses a lower base salary M_{ij} plus a distance-dependent commission function $\lambda l \mu M_{ij}$ with income $(1+\lambda l)M_{ij}$, where λ is the limit of distance commission (0<λ<1). It is also possible to quantify and grade different long-distance or cross-regional orders, and then assign orders according to the distance.

At this point, it is necessary to consider the timeliness as well as the reference transportation for pricing and constructing the reward and punishment model.

4. Result

4.1 Rider's time-out program design

For incentives and disincentives set time windows:

Table 3. Time Window

Symbols	Symbol Description
t	Actual delivery time
t(1)	Ideal delivery time
t(2)	The latest delivery time acceptable to the customer
t(3)	The latest delivery time acceptable to the customer
t(4)	The latest point of the third time window for successful delivery

Secondly, establish a rewards and punishment module.

1) When t<t(1): the highest customer satisfaction, i.e. the rider has the highest service quality, gets the complete delivery amount, and is rewarded with a delivery commission at this time.

2) When t(1)<t<t(2): average customer satisfaction, i.e. the rider has average service quality, gets the complete delivery amount, and has no delivery commission.

3) When t(2)<t<t(3), customer satisfaction is unsatisfactory, i.e. the rider's service quality is not good for the customer at this time, and the corresponding delivery amount is deducted according to the delay, and the ordinary timeout is recorded once.

4) When t(3)<t<t(4), customer satisfaction is very unsatisfied, and there is a risk of order cancellation, that is, the rider is unable to deliver normally at this time, and according to the delay, the delivery amount with a higher coefficient will be deducted, and a serious timeout will be recorded.

5) When t>t(4), it causes extreme customer dissatisfaction and leads to order cancellation and delivery failure, the rider needs to bear the maximum penalty M and record "order cancellation due to rider" once.

The efficiency of riders in delivering monthly orders on time and their monthly pay is established as follows:

1) When the monthly on-time rate falls below 0.98, $0.2 will be deducted from the rider's pay per order, and the total deduction will be 0.2*t.

2) When the monthly on-time rate falls below 0.96, $0.4 will be deducted from the rider's pay per order and the total deduction will be 0.4*t, and so on, with a maximum deduction of $1 per order for the rider.

3) Riders with serious overtime will be deducted 20 RMB once.

4.2 Multiple linear regression equation about time

1) Steps

a) Deriving the judgment matrix

The matrix A of external influences and the matrix B of internal influences are obtained by comparing the discriminant matrices as follows. The judgment matrix for the three indicators of external factors is constructed as follows:

$$A=\begin{pmatrix}1 & 2 & 2\\ 1/2 & 1 & 1/2\\ 1/2 & 2 & 1\end{pmatrix} \tag{6}$$

The A judgment matrix is constructed for the three indicators of internal factors, namely, as follows:

$$B = \begin{pmatrix} 1 & 1/3 & 1/2 \\ 3 & 1 & 2 \\ 2 & 1/2 & 1 \end{pmatrix} \tag{7}$$

b) Hierarchical single ranking and its consistency test

The maximum eigenv1alue of matrix A is λ_1= 3.05 and the maximum eigenvalue of matrix B is λ_2= 3.01 using python.

The consistency test was performed using the T.L. Saaty consistency index:

$$CI_1 = \frac{(\lambda_1 - n)}{n-1} = 0.025,$$

$$CI_2 = (\lambda_2 - n)/(n-1) = 0.005 \tag{8}$$

According to Satty's stochastic consistency index, we get RI_1 = 0.54, RI_2 = 0.63. and the consistency ratio is:

$$CR_1 = \frac{CI_1}{RI_1} = \frac{0.025}{0.54} = 0.046 \prec 0.1,$$

$$CR_2 = CI_2/RI_2 = \frac{0.005}{0.63} = 0.0079 \prec 0.1 \tag{9}$$

That is, it passed the consistency test.

c) Calculation of influence factors (indicators) weights (retain three decimal places)

In calculating the weights of the factors, the influence of extreme weather is not considered, and only the influence of general weather is considered. The following formula is established:

$$f(x) = \mu \cdot M_j \tag{10}$$

$$F(t) = a_1 \cdot W_q + a_2 \cdot R_k + a_3 \cdot t_q + a_4 \cdot g + a_5 \cdot t_i + a_6 \cdot t_s \tag{11}$$

$$\begin{cases} \mu = 0, & F(t) \leqslant t(2) \\ \mu = 0.20 & , t(2) \leqslant F(t) \leqslant t(3) \\ \mu = 0.40 & t(3) \leqslant F(t) \leqslant t(4) \end{cases} \tag{12}$$

And because the influence of extreme weather is not considered, the precondition a_1= 0 is considered, then $a_1 W_q = 0$, which gives the following equation:

$$F(t) = a_2 \cdot R_k + a_3 \cdot t_q + a_4 \cdot g + a_5 \cdot t_i + a_6 \cdot t_s \tag{13}$$

From (8) (10) (11) the base salary of the rider is calculated as $M_j = 5$. The weights of the final influencing factors are obtained in the following table.

Table 4. Results of secondary indicator weights

Tier 1 Indicators	Weights	Secondary indicators	Weights a_i
External Factors Tier 1 Indicators	0.500	Weather	0.079
		Road conditions	0.260
		Pick-up time	0.143
External Factors	0.500	Meal weight	0.247
		Service attitude	0.098
		Delivery time	0.155

Among them, the specific effects brought by each influencing factor on the actual delivery time are as follows:

$$\begin{cases} W_q = k_1 t \\ R_k = k_2 t \\ t_q = k_3 t \\ g = k_4 t \\ t_i = k_5 t \\ t_s = k_6 t \end{cases} \tag{14}$$

Where $k_i (i = 1,2,3,4,5,6)$ is the decision coefficient of each influence factor versus time.

Thus, a new reward and punishment scheme is proposed on this basis [21] by adding the increment $\Delta t = (k_1 + \ldots + k_6)$ into the time window in Problem 1 to obtain:

$$\begin{cases} t(11) = t(1) + \Delta t \\ t(21) = t(2) + \Delta t \\ t(31) = t(3) + \Delta t \\ t(41) = t(4) + \Delta t \end{cases} \tag{15}$$

The reward and punishment scheme applicable to this question is obtained by substituting the new time window into the reward and punishment scheme in the previous section.

2) Expansion

Based on the previous section, focusing on the effect of extreme weather, then k_1 is not equal to 0 at this point.

a) Drawdown design scheme

According to (8), $f(x) = \mu \cdot M_j, M_j$ is the base salary for each order delivered by the rider.

b) On the amount of additional order delivery fee charged

Assuming that the $f(x)$ found in the second question is denoted as $f(x_1)$, and the value of $f(x)$ required in this question is denoted as $f(x_2)$, then $\Delta f(x) = f(x_2) - f(x_1)$. At this point, $\Delta f(x)$ is the additional delivery cost incurred for delivering orders in bad weather, and it should be noted that this additional cost $\Delta f(x)$ is borne by the merchant.

c) Order delivery time design

According to the (8) (9) (10) established in Problem 2, the order delivery time can be understood as the following equation:

$$t' = t + \Delta t \tag{16}$$

Where Δt is the additional delivery time generated by delivering orders in extreme (bad) weather, and t is $\mathrm{t = t(q) + t(s) + t(e)}$.

4.3 Two-stage game model

Tabulation and analysis of the situation:

Table 5. Game Matrix 1

	Platform bias for riders		Platforms favor merchants	
	Self-delivery	Platform Delivery	Self-delivery	Platform Delivery
Riders choose to work overtime	(R_1, P_1, H_1)	(R_1, P_2, H_1)	(R_2, P_1, H_1)	(R_2, P_2, H_1)
Riders do not choose to work overtime	(R_1, P_1, H_2)	(R_1, P_2, H_2)	(R_2, P_1, H_2)	(R_2, P_2, H_2)

Table 6. Game Matrix 2

	Customer Choice Platform	Customers choose merchants
Yes	(U_1, M_1)	(U_1, M_2)
No	(U_2, M_1)	(U_2, M_2)

From the above two tables, we can see that the maximization scheme of the platform's benefit is $max(R_1, R_2)$, and considering the manpower loss brought by the merchant's independent delivery, we can get the maximization scheme of the merchant's benefit is (P_1, R_2) The maximization scheme of the rider's benefit is (R_2, H_2), and the maximization scheme for the customer's benefit is (P_2, R_2).

In this paper, considering the win-win situation and improving the overall happiness index of the society as much as possible, we give priority to the part with more people, and consider the satisfaction of customers for the delivery time to make the following plan: customers choose merchants to pursue faster delivery, the gain is M_2, and the platform makes concessions, the gain is U_1. The final solution is:

$$\{R_1, P_2, H_1, M_2, U_1\}.$$

5. Conclusion

The model established in this paper discusses the influence of various factors on the delivery time, and finally obtains a total delivery time and determines the salary commission of employees according to the time and on-time rate. The model can be extended to estimate the time of cold chain fresh food transportation, and then refine the cold chain transportation methods and approaches from the perspective of time. The model can also be used for services such as online grocery shopping, as well as for transportation processes that require strict time requirements. And in the courier industry, which is similar to the takeaway industry, the model established in this paper can also be a good solution to the courier's salary commission scheme and further constrain and refine the courier's delivery time, which helps the courier industry's service level to grow.

The game theory approach can also be applied to the optimization of production costs, the location of some buildings, etc. It is possible to improve the satisfaction of all parties in the production process to reach a state of equilibrium called Nash equilibrium and maintain the stability of the industry.

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