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Logistics Service Mode Selection for Last Mile Delivery: An Analysis Method Considering Customer Utility and Delivery Service Cost

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Abstract: Last mile delivery is an important part in the logistics service process of express enterprises since it can directly contact with the customer and affect customer satisfaction. How to select a suitable logistics service mode for last mile delivery with the objectives of lower delivery service cost and higher customer satisfaction is a noteworthy research topic. In this paper, we focus on the analysis method for logistics service mode selection for last mile delivery considering customer utility and delivery service cost. First, we conduct the market survey of customer needs and discuss the market segmentation, and then we propose a customer utility value calculation model based on utility theory. Next, we propose a delivery quantity prediction method based on the time series prediction and customer selection probability calculation. Furthermore, we construct a cost accounting model to determine the delivery service cost. On this basis, we show the selection of the suitable logistics service mode for last mile delivery according to the analysis results of customer utility and delivery service cost. Finally, we show the feasibility and effectiveness of the proposed method by a case analysis.

Keywords: last mile delivery; logistics service mode selection; customer utility; delivery service cost



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1. Introduction

Internet consumption accelerates the development of the express industry in China [1]. In 2019, more than 63 billion parcels have been delivered by express enterprises, and the average delivery parcels for each customer was 45. In 2020, the novel coronavirus pneumonia outbreaks led to the sharp development of the express industry. The volume of China's express delivery service has been highest in the world for six years [2]. With the rapid development of express delivery industry and especially e-commerce, the logistics service has shown the characteristics of small pieces, large quantities, high frequency, the wide dispersion of recipients, constrained delivery time window, and high delivery failure rates.

The last mile delivery is an important link of express service, and it is directly related to the logistics service performance. The last mile delivery refers to the delivery process of the parcels purchased by the customer from the end delivery station to the customer or the pick-up location designated by the customer (such as self-pick-up locker) [3]. So, the last mile delivery usually has the characteristics of high cost, low efficiency and high pollution, and limits the development of express enterprises [4,5]. According to statistics, the last mile delivery service cost accounts for 13–75% of the total cost of the entire supply chain [6]. Furthermore, in the whole process of packaging, loading and unloading, transporting, sorting and delivering to customers, last mile delivery is the only link to face the customer.

The delivery efficiency and the service attitude of the deliveryman directly influence the customer satisfaction, and customer satisfaction is very important for express enterprises to enhance their competitive advantages [7].

The main purpose of this paper is to study the analysis method for logistics service mode selection for last mile delivery considering the two dimensions of customer utility and delivery service cost from the perspective of express enterprises. Specifically, by analyzing direct delivery mode, indirect delivery mode, and combined delivery mode, we propose a method for logistics service mode selection for last mile delivery based on a “utility-cost” two-dimensional decision matrix model. The proposed method can help express enterprises to select the most suitable logistics service mode for last mile delivery in different stages, and further to achieve the purpose of reducing cost, improving profitability, and enhancing customer satisfaction. Thus, the market competitiveness of express enterprises can be promoted.

The main contributions of our work are as follows. First, we propose the combined delivery mode, and develop the calculation models for customer utility and delivery service cost, respectively. Secondly, we analyze and consider the impacts of the related factors of customer selection behavior on the logistics service mode for last mile delivery, and develop an analysis method for customer selection behavior and customer utility calculation model. Thirdly, we discuss the delivery quantity prediction method and delivery service cost accounting method with respect to last mile delivery. On this basis, we develop the analysis method for logistics service mode selection for last mile delivery considering customer utility and delivery service cost.

Our study has theoretical value and practical importance. In theory, we analyze the impacts of the delivery service cost and customer satisfaction on logistics service mode selection decision for last mile delivery, and propose a new method to solve the logistics service mode selection problem for last mile delivery considering delivery service cost and customer satisfaction. Our study can enrich theoretical research results and extend theoretical research scope on logistics service mode selection for last mile delivery. In practice, express enterprises need the theoretical research results to guide them in the logistics service mode selection, our method can guide them to make the optimal decision on the logistics service mode selection for last mile delivery. Our study is different from the existing research results since we simultaneously consider the impacts of delivery service cost and customer satisfaction and provide a feasible way to logistics service mode selection problem for last mile delivery.

The remainder of the paper is organized as follows: Section 2 summarizes the relevant literature. Section 3 gives the description of logistics service modes for last mile delivery, basic assumptions and notations. Section 4 analyzes the customer utility and gives its calculation model. In Section 5, the calculation model of delivery service cost is given. Section 6 gives the method for logistics service mode selection for last mile delivery considering customer utility and delivery service cost. Section 7 conducts a case analysis. Finally, Section 8 summarizes the main conclusions and shows the further research work.

2. Literature Review

Olsson (2019) pointed out that last mile delivery has been an emerging research area in the past five years [5]. The rapid development of last mile delivery is mainly driven by accelerated urbanization and population growth [8], e-commerce development [9,10], the change of consumer behavior [9,11], innovation [12] and application of new technology [13]. In addition, some factors can affect the logistics service of express enterprises, such as delivery service cost, delivery capacity, delivery efficiency, customer satisfaction, customer selection behavior and carbon emissions [14–17]. In this study, we mainly focus on the impacts of customer utility and delivery service cost. Obviously, the research related to this study mainly involves the following three aspects, i.e., the customer utility in last mile delivery service, the delivery service cost in last mile delivery service, and the logistics service mode selection. In the following, we provide the specific analysis.

For the research on the delivery service cost in last mile delivery service, for examples, Wang et al. [18] analyzed the advantages and disadvantages of each logistics service mode for last mile delivery, constructed related models to calculate the delivery service cost of each mode. Gevaers et al. [19] studied the cost of B2C last mile delivery in urban areas by quantitative analysis and situational simulation, and found the critical cost impact factors.

For the research on the customer satisfaction in logistics service, for example, Le et al. [20] used the structural equation modeling (SEM) technology to analyze the five determinants of service quality and customer satisfaction, and found that the service quality of express enterprises had a positive impact on customer satisfaction. Liu et al. [21] used Kano model to analyze the impacts of delivery service factors on the customer satisfaction, and provided relevant suggestions on how to further meet customer needs. Xu et al. [22] used the binary logit model to analyze the main impact factors of customer satisfaction in logistics service, and verified that facilities, economics and convenience had significant impacts on customer satisfaction.

In addition, there are some research results on logistics service considering delivery service cost and customer satisfaction, for example, Wang et al. [23] provided an optimal alternative for the terminal delivery in cold chain logistics based on the vehicle routing optimization model considering delivery service cost and customer satisfaction. Deng et al. [24] studied the relation between supply chain cost and customer satisfaction, and developed a multi-objective programming model considering the customer time satisfaction degree. Liu et al. [25] proposed the practice insights for express enterprises from the three dimensions of customer loyalty, satisfaction and logistics cost, and illustrated that the balance of logistics cost and customer satisfaction is an important for express enterprises.

We can see from above analysis that the most existing research results mainly consider the single-dimensional factor such as delivery service cost or customer satisfaction from the perspective of express enterprises. They do not involve the impact of customer acceptance degree for different logistics service modes on the mode selection. For the studies with delivery service cost and customer satisfaction, the existing results mainly focus on vehicle routing optimization or carbon emissions, do not involve the logistics service mode selection for last mile delivery. Moreover, the existing research results only involve service elements in cost accounting, they do not involve process cost analysis and cost accounting models for some specific logistics service modes. Therefore, it is necessary to analyze customer satisfaction and customer choice behavior, and to study cost model and quantitative calculation for different logistics service modes for last mile delivery.

For the research on the logistics service mode selection method, there are three main aspects, i.e., the selection method based on Ballou two-dimensional matrix, the selection method based on analytic hierarchy process (AHP) and other selection methods [26–29]. For the research on the selection method based on Ballou two-dimensional matrix, for example, Ballou [26] innovatively established a two-dimensional decision-making model based on the qualitative analysis method, considered the two key factors in the decision-making of logistics service mode selection for express enterprises, and proposed Ballou model theory and perfected the theoretical system of logistics service mode selection. For the research on the selection method based on AHP, for example, Sun and Xue [27] established a logistics service mode selection model based on AHP using the combination of qualitative and quantitative research methods. In addition, some scholars have begun to study new decision-making methods for the logistics service mode selection, such as the TOPSIS method [28] and comprehensive analysis and evaluation method [29]. It is necessary to point out that most of them are quantitative comparison methods for single index or comprehensive analysis and evaluation methods, where AHP is extensively used in logistics service mode selection, but the accuracy of the results cannot be guaranteed by these qualitative analysis methods. Ballou two-dimensional matrix method provides a different way to solve logistics service mode selection problem, but the most concerning factor of the enterprise, i.e., the management cost, is ignored in the model establishment process, causing great limitations in the actual application of the model. Therefore, we

need to enrich and perfect existing methods by adopting new decision-making dimensions and quantitative methods.

The existing research results have made great contributions to the study on logistics service mode selection, and addressed some useful conclusions. It is necessary to point out that most existing results only consider one out of delivery service cost and customer satisfaction, but these two factors can simultaneously affect the optimal decision of express enterprises in practice, so the existing research results are not suitable to solve the logistics service mode selection problem for last mile delivery considering delivery service cost and customer satisfaction. Particularly, there are two highly related references in our study, i.e., literature [18] and literature [23]. Our study is different from theirs. For literature [18], Wang et al. calculated quantitatively delivery service cost of three delivery service modes considering the customer satisfaction. However, for our study, we develop the cost calculation model for six different delivery service modes, and consider the impact of customer satisfaction on logistics service mode selection for last mile delivery. For literature [23], Wang et al. focused on the impacts of delivery service cost and customer satisfaction on the terminal distribution scheme considering customers' time requirements from the perspective of vehicle routing optimization. However, for our study, we consider a new factor based on literature [23], i.e., customer behavior choices, and analyzed its impact on the logistics service mode selection for last mile delivery. Obviously, our study is different from the existing research results, and has theoretical value and practical significance.

3. Logistics Service Mode Description, Assumptions and Notations

The logistics service modes for last mile delivery mainly contain three types, i.e., direct delivery mode, indirect delivery mode and combined delivery mode. In the following, we provide the specific illustrations.

- (1) Direct delivery mode (home delivery mode) refers to a kind of logistics service mode in which the parcels are directly delivered from the last mile delivery service station to the customer and signed by the customer face to face. This mode has the advantages of high safety, high reliability and high customer satisfaction. It also has some disadvantages, for example it is not suitable for handling many orders, the failure rate of first-time delivery and the delivery service cost are high, and the delivery service efficiency is lower.
- (2) Indirect delivery mode refers to a kind of logistics service mode in which the parcels are delivered to the self-pick-up location assigned by express enterprises, the self-pick-up location is usually near the customer, and in cooperation with the third party for the transportation and operations. In this mode, the parcel will be picked up by the customer from the self-pick-up location. This mode has some advantages of saving labor costs, reducing the failure rate of first-time delivery, improving the delivery service efficiency, and having flexible self-pick-up time. It also has disadvantage that the customer needs to go to the self-pick-up location. For this mode, the face-to-face communication is not involved, so the customer cannot enjoy value-added services, such as cash on delivery and unpacking inspection, and customer satisfaction is low.

It is necessary to point out that indirect delivery mode mainly includes four forms, i.e., Self-pick-up locker form, Cooperation form with convenience store (or property company), Cooperation form with Cainiao Station, and Self-pick-up store form. The specific illustrations are as follows:

For Self-pick-up locker form, the deliveryman delivers the parcel to the nearest or assigned self-pick-up locker of the customer and the customer receives the number of the box and the code needed to unlock the box.

For Cooperation form with convenience store, the deliveryman delivers the parcel to the convenience store or property company near the customer or assigned by the customer, and the customer can visit it to pickup service on the way home.

For Cooperation form with Cainiao Station, the deliveryman delivers the parcel to the fourth-party logistics service platform of Cainiao Station near the customer or assigned by the customer, then the customer can pick up the parcel by a self-pick-up code from Cainiao Station. It is necessary to note that Cainiao Station is a kind of solution for last mile delivery established by Alibaba Group.

For Self-pick-up store form, the express enterprise establishes its own store in the delivery area (such as SF Heike), and deliveryman delivers the parcel to the store, and then the customer picks it up by himself.

- (3) Combined delivery mode refers to a kind of logistics service mode which combines the direct delivery mode and the indirect delivery mode. This mode can make up for the disadvantages of a single delivery mode, and meet the delivery service needs of different customers, and further improve the customer satisfaction. In addition, this mode can reduce the failure rate of first-time delivery through reasonable delivery plan, and further improve the delivery service efficiency and reduce delivery service cost. In this mode, the customers can choose the appropriate delivery service from according to their own situation. For this mode, the way of picking up is flexible, and the delivery service needs of the customer can be met.

To clearly present the description of our study, we make the following assumptions [30].

Assumption (1). *The express enterprise is in noncompetition of the regional last mile delivery market, and customers have not loss. The success rate of second-time delivery of the express enterprise is 100%.*

Assumption (2). *The customer can choose the delivery service form from the potential logistics service modes.*

Assumption (3). *The customer can fully understand the attributes information of the logistics service mode, and the attributes are independent each other.*

Assumption (4). *The customer can measure the utility of each logistics service mode, and can choose the delivery mode with the optimal utility.*

To facilitate analysis and calculation, we define and explain the symbols involved in this study in the following.

4. The Customer Utility

The customer utility refers to the satisfaction degree of the customer in the rational consumption with limited resources [31], i.e., customer satisfaction. The higher the customer satisfaction is, the greater the quantity of customers is. The customer satisfaction is related to the customer preference. Therefore, express enterprises need to consider customer preference to different logistics service modes for last mile delivery, and select the logistics service mode that can meet the customer needs.

In this study, we use a questionnaire survey method to obtain the customer preference, and use the cluster analysis technology, i.e., K-means algorithm, to segment the market. Then, we calculate the utility value of all kinds of customers for different logistics service modes in each market segment, and calculate the total customer utility value of each logistics service mode. Finally, we construct the calculation model of the customer utility value.

4.1. Customer Demand Survey and Market Segmentation

By combing and analyzing the research results on the impact factors of logistics service mode selection of the customer [32,33], we determine the main factors that can affect the customer choice behavior with respect to the logistics service mode for last mile delivery, i.e., self-pick-up distance, parcel security, pick-up time window, service quality and value-added service. On this basis, we conduct the survey on the customer selection preference

and obtain the information from the customer about the weight of each attribute and the acceptance degrees for different attribute values in each logistics service mode for last mile delivery. The information provides the data basis for the further calculation of customer utility value. For the valid questionnaires, the SPSS is used to analyze the data.

Market segmentation is to integrate the customers with the same or similar characteristics. Express enterprises cannot meet the needs of each customer in the logistics service mode selection decision for last mile delivery. Therefore, for the objective segment market, express enterprises should pay more attention to satisfy the need of the high value customer. Here, the market is segmented according to the weight of the customer with respect to logistics service mode attributes for last mile delivery, and the selected segmentation variables are the weight values of the above five factors, then K-means algorithm is used to conduct the market segmentation according to the analysis in the relevant literature [34]. For N customers in the market, the K-means algorithm can divide these customers into K segmented market, the specific steps are as follows [35].

- (1) Determining the market segmentation variables, i.e., clustering variables.
- (2) Inputting cluster number and the data about the weight of the customer with respect to the logistics service mode attributes [36].
- (3) Setting the appropriate number of iterations M after repeated experiments [37].
- (4) Generating randomly initial clustering centers.
- (5) Calculating the distance from the individual to each clustering center, assigning the individual to the clustering center with the closest distance, and generating a new clustering center.
- (6) Judging whether the number of iterations is more than M , if so, outputting the final clustering result; if not, repeating step 5.

Furthermore, the specific steps in SPSS can be determined.

- (1) Importing the questionnaire data into SPSS, and numbering the data.
- (2) Selecting the K-means clustering option, and selecting the variables, i.e., the customer importance degree value of the self-pick-up distance, parcel security, pick-up time window, service quality and value-added service, into the "variable" column, and the select "customer number" into the "case label" column.
- (3) Determining the customer segments number K , and inputting K as the cluster number.
- (4) Setting the number of iterations M after repeated experiments.
- (5) Outputting the clustering results.

4.2. Calculation and Analysis of Customer Utility

According to the above analysis, we can determine the main impact factors of the customer utility in each logistics service mode for last mile delivery, i.e., self-pick-up distance, parcel security, pick-up time window, service quality and value-added service. From assumptions 3 and 4, we know that the customer utility value is the sum of the customer utility value of each factor. From Table 1, the customer utility function of the k th logistics service mode S_k in the i th market segment can be determined, i.e.,

$$V_{ik} = \sum_{n=1}^N w_{in} Q_{ikn}. \quad (1)$$

If k denotes the combined delivery mode, there are some differences. Let a represent home delivery mode, and b represent the self-pick-up delivery mode. Customers in the market segment tend to choose the one of modes a and b with greater utility value in the combined delivery mode. Then, the customer utility function of the k th logistics service mode S_k in the i th market segment can be rewritten as

$$V_{ik} = \text{Max}(V_{ika}, V_{ikb}). \quad (2)$$

where the values of V_{ika} and V_{ikb} are the same as the customer utility value of each other logistics service mode.

Table 1. Symbols and descriptions of customer utility and delivery quantity.

| Symbols | Descriptions | Symbols | Descriptions |
|-----------|---|-----------|--|
| I | The total number of market segments ($i = 1, 2, \dots, I$). | w'_i | The customer importance degree value for the express enterprise in the i th market segment (the value will be determined by the express enterprise). |
| T_t | The number of the last mile delivery areas ($t = 1, 2, \dots, 10$). | V'_k | The total customer utility to the k th logistics service mode S_k . |
| K | The number of logistics service mode types that express enterprises can choose ($k = 1, 2, \dots, K$). | P'_k | The total customer selection probability of the k th logistics service mode S_k . |
| N | The number of attributes of logistics service mode ($n = 1, 2, \dots, N$). | a | The home delivery mode in combined delivery mode. |
| S_k | The k th logistics service mode. | b | The self-pick-up delivery mode in combined delivery mode. |
| a_{kn} | The attribute value of the n th attribute in the k th logistics service mode. | V_{ika} | The utility of the customer for the part a in the k th combined delivery mode in the i th market segment. |
| Q_{ikn} | The preference value of the customer with respect to a_{kn} in i th market segment (the value can be obtained by questionnaire survey). | V_{ikb} | The utility of the customer for the part b in the k th combined delivery mode in the i th market segment. |
| w_{in} | The weight value of the customer with respect to the n th attribute in the i th market segment (the value can be obtained by questionnaire survey). | Q_{ik} | The delivery quantity for the k th delivery mode in the i th market segment. |
| V_{ik} | The customer utility of the k th logistics service mode S_k in the i market segment. | Q'_k | The total delivery quantity for the k th delivery mode. |
| P_{ik} | The customer selection probability of the k th logistics service mode S_k in the i th market segment. | | |

By Equations (1) and (2), the customer utility of each logistics service mode for last mile delivery in each market segment can be determined. Then, according to the importance degree w'_i of each market segment to express enterprises, the total customer utility value for each logistics service mode can be determined, i.e.,

$$V'_k = \sum_{i=1}^I w'_i V_{ik}. \quad (3)$$

5. Delivery Service Cost

The other main impact factor of logistics service mode selection for last mile delivery is delivery service cost. Gevaers et al. [19] illustrated the relationship between the cost accounting model for last mile delivery and the piece wage of deliveryman, showed that delivery service cost is a function of the delivery quantity. In this study, we use the time series prediction method [38] to predict the delivery quantity of a single logistics service mode, and use the time series prediction and customer selection probability calculation to predict the delivery quantity of each logistics service mode in the combined delivery mode. Furthermore, the delivery service cost can be determined by the cost accounting model.

5.1. Customer Selection Probability

According to the literature [39,40], we use multiple logit model to calculate the customer selection probability. From Table 1, the customer selection probability of the k th logistics service mode S_k in the i th market segment can be determined, i.e.,

$$P_{ik} = e^{V_{ik}} / \sum_{k^*=1}^K e^{V_{ik^*}}. \quad (4)$$

Further, the total customer selection probability to the k th logistics service mode S_k can be determined, i.e.,

$$P'_k = e^{V'_k} / \sum_{k^*=1}^K e^{V'_{k^*}}. \quad (5)$$

5.2. Delivery Quantity Prediction of Different Logistics Service Modes

For a single logistics service mode, we provide a delivery quantity prediction method. The specific steps are as follows. First, the historical delivery quantity data of the express enterprise at the delivery point (the value can be obtained by the express enterprise) will be analyzed. Then, a suitable fitting model will be selected to fit the historical delivery quantity. As the delivery quantity of express enterprises generally increases year by year, the time series prediction method is adopted, and the relevant fitting models as shown in Table 2 are also used. Here, Q' denotes the delivery quantity of the last mile delivery service station, x denotes the independent variable (time), and b_i denotes the regression coefficient, $i = 0, 1, 2$) [38]. Furthermore, the optimal prediction fitting model can be determined by the regression equation significance test (i.e., F test), regression coefficient significance test (i.e., T test) and fitting degree R^2 value (i.e., sample determination coefficient) for these fitting models using SPSS.

Table 2. Time series prediction fitting mode.

| Fitting Models | Symbolic Representations | Expressions |
|-----------------------|--------------------------|----------------------------|
| Quadratic curve model | Q_u Model | $Q' = b_0 + b_1x + b_2x^2$ |
| Power function model | P_o Model | $Q' = b_0x^{b_1}$ |
| S-shaped curve model | S_s Model | $Q' = e^{(b_0+b_1/x)}$ |
| Growth curve model | G_r Model | $Q' = e^{(b_0+b_1x)}$ |

According to the determined optimal prediction method, the delivery quantities for single and combined logistics service modes are predicted, respectively, and the optimal delivery quantity prediction can be determined, i.e.,

$$Q' = f(x). \quad (6)$$

It is necessary to note that, if the express enterprise selects and uses a single logistics service mode, the delivery quantity can be calculated by Equation (6). If the express enterprise selects and uses combined logistics service mode, for the i th market segment, the delivery quantity for the k th logistics service mode can be determined, i.e.,

$$Q_{ik} = P_{ik}Q' = P_{ik}f(x). \quad (7)$$

If the express enterprise selects and uses a combined logistics service mode, for the whole market, the delivery quantity for the k th logistics service mode can be determined, i.e.,

$$Q'_k = P'_kQ' = P'_k f(x). \quad (8)$$

5.3. Delivery Service Cost of Different Logistics Service Modes

In the logistics service process for last mile delivery, some costs are involved. These costs mainly contain fixed cost, basic delivery service cost and reverse delivery service cost. According to the three costs, the total delivery service cost of each logistics service mode can be determined, then the dynamic delivery service cost accounting model can be constructed [19,41].

5.3.1. Cost Analysis for Home Delivery Mode

The home delivery service cost includes the fixed cost, the basic delivery service cost and the reverse delivery service cost. Then the total cost C_D can be determined, i.e.,

$$C_D = C_{DF} + C_{DP} + C_{DR}. \quad (9)$$

(1) The fixed cost

From Table 3, the daily fixed cost $C_{DF}(Q)$ can be determined, i.e.,

$$C_{DF}(Q) = SW + \frac{Q}{Q_{v1} \times DT_1} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_1 \right). \quad (10)$$

where $Q/(Q_{v1} \times DT_1)$ denotes the number of basic facilities and equipment, and its value is an integer.

Table 3. Symbols and descriptions of home delivery mode.

| Symbols | Descriptions | Symbols | Descriptions |
|------------|---|---------|---|
| C_D | The total delivery service cost. | L_j | The period of depreciation. |
| C_{DF} | The fixed cost. | SW | The daily salary and benefit of manager. |
| C_{DP} | The basic delivery service cost. | TW | The daily basic salary and benefit of deliveryman. |
| C_{DP}^1 | The first-time delivery service cost. | IM_1 | The daily cost of each facility and equipment. |
| C_{DP}^2 | The second-time delivery service cost. | PR_1 | The commission of each parcel delivered by the deliveryman. |
| C_{DR} | The reverse delivery service cost. | e_1 | The cost of fuel (or electricity) consumption for each parcel delivery. |
| C_{DR}^1 | The basic cost of reverse delivery. | v | The vehicle type coefficient, which is used to describe the impact of vehicle types on basic delivery service costs. |
| C_{DR}^2 | The additional processing cost. | win | The time window coefficient, which is used to describe the change in the number of delivered parcels for each deliveryman due to the customer time constraints. |
| Q | The daily delivery quantity. | ip | The success probability of first-time delivery. |
| Q_{v1} | The quantity of parcels to be delivered each time. | z_1 | The coefficient of additional cost in the delivery service process, such as communication fees. |
| DT_1 | The daily delivery times each vehicle. | r | The probability of reverse delivery service cost caused by customer rejection, return, etc. |
| j | The equipment type. $j = 1$ denotes the delivery vehicle; $j = 2$ denotes the handheld terminal. | ht | The time to process each parcel in reverse delivery. |
| PC_j | The equipment purchase cost | lc | The cost to process parcels each time in reverse delivery. |
| α_j | The salvage rate ($0 < \alpha_j < 1$), which is used to describe the ratio of recoverable cost to purchase cost when the equipment is scrapped. | | |

(2) The basic delivery service cost

The cost C_{DP} is composed of C_{DP}^1 and C_{DP}^2 . C_{DP}^1 and C_{DP}^2 mainly include the labor cost, the vehicle operation cost and the additional cost. From Table 3, for daily delivery quantity Q in the delivery area, the first-time delivery service cost $C_{DP}^1(Q)$ can be determined, i.e.,

$$C_{DP}^1(Q) = Q \times (ip \times PR_1 + e_1 \times v \times win + z_1). \quad (11)$$

According to $C_{DP}^1(Q)$ and success probability ip of first-time delivery, the second-time delivery service cost $C_{DP}^2(Q)$ can be determined, i.e.,

$$C_{DP}^2(Q) = Q \times (1 - ip) \times (PR_1 + e_1 \times v \times win + z_1). \quad (12)$$

Then, C_{DP} can be further determined, i.e.,

$$C_{DP}(Q) = C_{DP}^1(Q) + C_{DP}^2(Q) = Q \times (ip \times PR_1 + e_1 \times v \times win + z_1) + Q \times (1 - ip) \times (PR_1 + e_1 \times v \times win + z_1). \quad (13)$$

(3) The reverse delivery service cost

The cost C_{DR} is composed of C_{DR}^1 and C_{DR}^2 . C_{DR}^1 is divided into two parts, one part is caused by the failed first-time delivery of the parcel, the other is caused by the customer rejection, return or other reasons. The probability r of reverse delivery service can be obtained according to the previous annual data of the express enterprise in the delivery area. Furthermore, C_{DR}^1 can be determined, i.e.,

$$C_{DR}^1(Q) = Q \times e_1 \times v \times (1 - ip + r). \quad (14)$$

The cost C_{DR}^2 can be converted into the corresponding processing time cost. According to ht and lc , C_{DR}^2 can be expressed as

$$C_{DR}^2(Q) = Q \times r \times ht \times lc. \quad (15)$$

By Equations (14) and (15), C_{DR} can be determined, i.e.,

$$C_{DR}(Q) = C_{DR}^1(Q) + C_{DR}^2(Q) = Q \times e_1 \times v \times (1 - ip + r) + Q \times r \times ht \times lc. \quad (16)$$

By Equations (9), (10), (13) and (16), $C_D(Q)$ can be determined, i.e.,

$$C_D(Q) = C_{DF}(Q) + C_{DP}(Q) + C_{DR}(Q) = SW + \frac{Q}{Q_v \times DT_1} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_1 \right) + Q \times (ip \times PR_1 + e_1 \times v \times win + z_1) + Q \times (1 - ip) \times (PR_1 + e_1 \times v \times win + z_1) + Q \times e_1 \times v \times (1 - ip + r) + Q \times r \times ht \times lc \quad (17)$$

5.3.2. Cost Analysis for Self-Pick-Up Locker Form in Indirect Delivery Mode

When the Self-pick-up locker form is adopted, the reverse delivery service cost and the second-time delivery service cost are generally not involved. Then, the total cost C_L can be determined, i.e.,

$$C_L = C_{LF} + C_{LP}. \quad (18)$$

(1) The fixed cost

The cost C_{LF} mainly includes the fixed assets construction cost and the daily management cost. From Table 4, the daily fixed cost $C_{LF}(Q)$ can be expressed as

$$C_{LF}(Q) = SW + n \times LR + \frac{\lambda \times Q \times PC_0 \times (1 - \alpha_0)}{365 \times L_0} + \frac{Q}{Q_{v2} \times DT_2} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_2 \right). \quad (19)$$

where $Q/(Q_{v2} \times DT_2)$ denote the number of basic facilities and equipment, and its value is an integer.

(2) The first-time delivery service cost

The cost C_{LP} mainly includes the labor cost, the vehicle operation cost and the additional cost. The first-time delivery service cost $C_{LP}(Q)$ can be determined, i.e.,

$$C_{LP}(Q) = Q \times (PR_2 + e_2 \times v + z_2). \quad (20)$$

By Equations (19) and (20), $C_L(Q)$ can be determined, i.e.,

$$C_L(Q) = C_{LF}(Q) + C_{LP}(Q) = SW + n \times LR + \frac{\lambda \times Q \times PC_0 \times (1 - \alpha_0)}{365 \times L_0} + \frac{Q}{Q_{v2} \times DT_2} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_2 \right) + Q \times (PR_2 + e_2 \times v + z_2) \quad (21)$$

Table 4. Symbols and description of Self-pick-up locker form in indirect delivery mode.

| Symbols | Descriptions | Symbols | Descriptions |
|------------|---|-----------|--|
| C_L | The total delivery service cost. | n | The number of self-pick-up locker in delivery area. |
| C_{LF} | The fixed cost. | LR | The daily venue rent fees and other fees for each self-pick-up locker. |
| C_{LP} | The first-time delivery service cost. | IM_2 | The daily cost of each facility and equipment. |
| Q_{v2} | The quantity of parcels to be delivered each time. | PR_2 | The commission of each parcel delivered by the deliveryman. |
| DT_2 | The daily delivery times each vehicle. | e_2 | The cost of fuel (or electricity) consumption for each parcel delivery. |
| PC_0 | The average purchase cost of self-pick-up locker and supporting equipment for each package. | z_2 | The coefficient of additional cost in the delivery service process, such as communication fees. |
| α_0 | The salvage rate ($0 < \alpha_0 < 1$), which is used to describe the ratio of recoverable cost to purchase cost when the self-pick-up locker and supporting equipment are scrapped. | λ | The relationship coefficient ($\lambda > 1$) between the number of storage boxes and the average daily delivery quantity of parcels (the value is determined by the express enterprise). |
| L_0 | The period of depreciation. | | |

5.3.3. Cost Analysis for Cooperation Form with Convenience Store in Indirect Delivery Mode

From Table 5, the total cost C_O can be determined, i.e.,

$$C_O = C_{OF} + C_{OP}. \quad (22)$$

Table 5. Symbols and descriptions of Cooperation form with convenience store in indirect delivery mode.

| Symbols | Descriptions | Symbols | Descriptions |
|----------|--|------------|---|
| C_O | The total delivery service cost. | IM_3 | The daily cost of each facility and equipment. |
| C_{OF} | The fixed cost. | PR_3 | The commission of each parcel delivered by the deliveryman. |
| C_{OP} | The first-time delivery service cost. | e_3 | The cost of fuel (or electricity) consumption for each parcel delivery. |
| Q_{v3} | The quantity of parcels to be delivered each time. | z_3 | The coefficient of additional cost in the delivery process, such as communication fees. |
| DT_3 | The daily delivery times each vehicle. | σ_1 | The cost to convenience store paid for each parcel. |

(1) The fixed cost

The cost C_{OF} mainly includes the fixed assets construction cost and the daily management cost. From Table 5, the daily fixed cost $C_{OF}(Q)$ can be determined, i.e.,

$$C_{OF}(Q) = SW + \frac{Q}{Q_{v3} \times DT_3} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_3 \right). \quad (23)$$

(2) The first-time delivery service cost

The cost C_{OP} mainly includes the labor cost, the vehicle operation cost, the cooperation cost and the additional cost. Thus, the first-time delivery service cost $C_{OP}(Q)$ can be expressed as

$$C_{OP}(Q) = Q \times (PR_3 + e_3 \times v + \sigma_1 + z_3). \quad (24)$$

By Equations (23) and (24), $C_O(Q)$ can be determined, i.e.,

$$C_O(Q) = C_{OF}(Q) + C_{OP}(Q) = SW + \frac{Q}{Q_{v3} \times DT_3} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_3 \right) + Q \times (PR_3 + e_3 \times v + \sigma_1 + z_3). \quad (25)$$

5.3.4. Cost Analysis for Cooperation Form with Cainiao Station in Indirect Delivery Mode

From Table 6, C_N can be determined, i.e.,

$$C_N = C_{NF} + C_{NP}. \quad (26)$$

Table 6. Symbols and descriptions of Cooperation form with Cainiao Station in indirect delivery mode.

| Symbols | Descriptions | Symbols | Descriptions |
|----------|--|------------|---|
| C_N | The total delivery service cost. | IM_4 | The daily cost of each facility and equipment. |
| C_{NF} | The fixed cost. | PR_4 | The commission of each parcel delivered by the deliveryman. |
| C_{NP} | The first-time delivery service cost. | e_4 | The cost of fuel (or electricity) consumption for each parcel delivery. |
| Q_{v4} | The quantity of parcels to be delivered each time. | z_4 | The coefficient of additional cost in the delivery process, such as communication fees. |
| DT_4 | The daily delivery times each vehicle. | σ_2 | The cost to Cainiao Station paid for each parcel. |

(1) The fixed cost

By Equation (23), the daily fixed cost $C_{NF}(Q)$ is given by

$$C_{NF}(Q) = SW + \frac{Q}{Q_{v4} \times DT_4} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_4 \right). \quad (27)$$

(2) The first-time delivery service cost

By Equation (23), the first-time delivery service cost $C_{NP}(Q)$ can be determined, i.e.,

$$C_{NP}(Q) = Q \times (PR_4 + e_4 \times v + \sigma_2 + z_4). \quad (28)$$

By Equations (27) and (28), $C_N(Q)$ can be determined, i.e.,

$$C_N(Q) = C_{NF}(Q) + C_{NP}(Q) = SW + \frac{Q}{Q_{v4} \times DT_4} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_4 \right) + Q(PR_4 + e_4 \times v + \sigma_2 + z_4). \quad (29)$$

5.3.5. Cost Analysis for Self-Pick-Up Store Form in Indirect Delivery Mode

The delivery service cost for self-pick-up store form mainly includes the fixed cost and first-time delivery service cost. From Table 7, the total cost $C_S(Q)$ can be expressed as

$$C_S = C_{SF} + C_{SP}. \quad (30)$$

Table 7. Symbols and descriptions of Self-pick-up store form in indirect delivery mode.

| Symbols | Descriptions | Symbols | Descriptions |
|----------|--|-------------|--|
| C_S | The total delivery service cost. | IM_5 | The daily cost of each facility and equipment. |
| C_{SF} | The fixed cost. | L'_0 | The period of depreciation. |
| C_{SP} | The first-time delivery service cost. | PR_5 | The commission of each parcel delivered by deliveryman. |
| Q_{v5} | The quantity of parcels to be delivered each time. | e_5 | The cost of fuel (or electricity) consumption for each parcel delivery. |
| DT_5 | The daily delivery times each vehicle. | z_5 | The coefficient of additional cost in the delivery process, such as communication fees. |
| SR | The daily rent for store. | n | The number of stores in the delivery area. |
| PC'_0 | The cost of store equipment. | α'_0 | The salvage rate ($0 < \alpha'_0 < 1$), which is used to describe the ratio of recoverable cost to purchase cost when the store equipment is scrapped. |

(1) The fixed cost

The cost C_{SF} mainly includes the fixed assets construction cost and the daily management cost. Here, we assume that there is a service staff in the store, and his/her benefits are the same as the manager. From Table 7, the daily fixed cost $C_{SF}(Q)$ can be determined, i.e.,

$$C_{SF}(Q) = (n + 1) \times SW + n \times \left(SR + \frac{PC'_0 \times (1 - \alpha'_0)}{365 \times L'_0} \right) + \frac{Q}{Q_{v5} \times DT_5} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_5 \right). \quad (31)$$

(2) The first-time delivery service cost

The cost C_{SP} mainly includes the labor cost, the vehicle operation cost and the additional cost. The first-time delivery service cost $C_{SP}(Q)$ can be determined, i.e.,

$$C_{SP}(Q) = Q \times (PR_5 + e_5 \times v + z_5). \quad (32)$$

By Equations (31) and (32), $C_S(Q)$ can be determined, i.e.,

$$C_S(Q) = C_{SF}(Q) + C_{SP}(Q) = (n + 1) \times SW + n \times \left(SR + \frac{PC'_0 \times (1 - \alpha'_0)}{365 \times L'_0} \right) + \frac{Q}{Q_{v5} \times DT_5} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_5 \right) + Q \times (PR_5 + e_5 \times v + z_5) \quad (33)$$

5.3.6. Cost Analysis for Combined Delivery Mode

The combined delivery mode is considered as the combination of self-pick-up delivery mode and home delivery mode. The express enterprise provides the home delivery service to the customers who require to sign face-to-face, and provides self-pick-up delivery service to other customers. According to above analysis and Table 8, the total cost C_H can be expressed as

$$C_H = C_{HF} + C_{HP}. \quad (34)$$

Table 8. Symbols and descriptions of the combined delivery mode.

| Symbols | Descriptions | Symbols | Descriptions |
|----------|--|---------|---|
| C_H | The total delivery service cost. | DT_6 | The daily delivery times each vehicle. |
| C_{HF} | The cost of self-pick-up delivery mode of the part of parcels. | IM_6 | The daily cost of each facility and equipment. |
| C_{HP} | The cost of home delivery mode of the rest of the parcels. | e_6 | The cost of fuel (or electricity) consumption for each parcel delivery. |
| Q_{v6} | The quantity of parcels to be delivered each time. | P_a | The probability customers choose home delivery mode. |

By Equation (21), the daily fixed cost $C_{HF}(Q)$ of the self-pick-up parcels can be determined, i.e.,

$$C_{HF}(Q) = SW + n \times LR + \frac{\lambda \times (1 - P_a) \times Q \times PC_0 \times (1 - \alpha_0)}{365 \times L_0} + \frac{Q}{Q_{v6} \times DT_6} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_6 \right) + (1 - P_a) \times Q \times (PR_2 + e_6 \times v + z_2) \quad (35)$$

Therefore, the daily fixed cost $C_{HP}(Q)$ of the home delivered parcels can be determined, i.e.,

$$C_{HP}(Q) = Q \times P_a \times (PR_1 + e_6 \times v \times win + z_1). \quad (36)$$

By Equations (35) and (36), $C_H(Q)$ can be determined, i.e.,

$$C_H(Q) = C_{HF}(Q) + C_{HP}(Q) = SW + n \times LR + \frac{\lambda \times (1 - P_a) \times Q \times PC_0 \times (1 - \alpha_0)}{365 \times L_0} + \frac{Q}{Q_{v6} \times DT_6} \left(\sum_{j=1}^m \frac{PC_j \times (1 - \alpha_j)}{365 \times L_j} + TW + IM_6 \right) + (1 - P_a) \times Q \times (PR_2 + e_6 \times v + z_2) + Q \times P_a \times (PR_1 + e_6 \times v \times win + z_1) \quad (37)$$

6. The Logistics Service Mode Selection for Last Mile Delivery

Through the analysis on two dimensions, i.e., the delivery service cost and customer utility, for each logistics service mode for last mile delivery, the logistics service mode selection framework for last mile delivery can be constructed based on a two-dimensional matrix decision model, as is shown in Figure 1. In Figure 1, the horizontal and vertical axis denote the delivery service cost dimension C and the customer utility dimension V , respectively. Then the whole region can be divided into the four regions by the line of “median value” in the two-dimensional matrix decision model, i.e., Regions I, II, III, and IV.

Through the comprehensive analysis on the delivery service costs and customer utility of different logistics service modes for last mile delivery, the regions of the express enterprise for each logistics service mode can be determined. Then the express enterprise can select the suitable logistics service mode according to their actual situation [42]. In the following, we provide a brief illustration of the four regions.

Region I: The express enterprise in this region has characteristics of higher delivery service cost and higher customer utility, which can meet well customers' service needs. Therefore, the express enterprise needs to make efforts to reduce the operation and management cost and maintain the higher customer satisfaction.

Region II: The express enterprise in this region has characteristics of lower delivery service cost and higher customer utility, which can obtain higher customer satisfaction and strong market competitive advantages by the effective cost control. Therefore, the express enterprise makes efforts to improve themselves to be in this region.

Region III: The express enterprise in this region has characteristics of lower delivery service cost and lower customer utility. Generally, the express enterprise in the early establishment stage is in this region since it cannot better improve customer satisfaction. The express enterprise in this region may take differentiated competitive advantages and enhance market competitiveness.

Region IV: The express enterprise in this region has characteristics of higher delivery service cost and lower customer utility. The express enterprise in this region should make the improvement for the delivery service cost and customer utility.

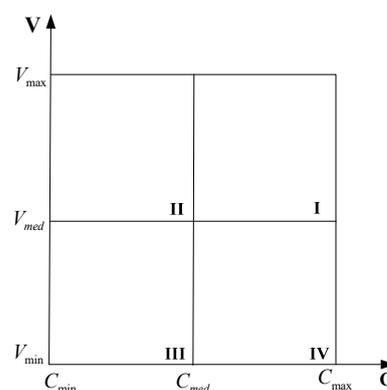


Figure 1. The two-dimensional matrix decision model for logistics service mode selection of last mile delivery.

7. Case Analysis

In this section, to show the feasibility and effectiveness of the proposed method, we take SS delivery center of AA Express in city B as an example to analyze the logistics service mode selection for last mile delivery. According to the geographical characteristics of the service area for last mile delivery and the delivery quantity, AA Express divides the SS delivery center into 10 delivery areas as shown in Figure 2, the corresponding daily delivery quantities set is $Q = \{Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, Q_7, Q_8, Q_9, Q_{10}\}$. Since there was no Cainiao Station in the area, the alternative logistics service modes for last mile delivery are home delivery mode, Self-pick-up locker form in indirect delivery mode, Cooperation form with

convenience store in indirect delivery mode, Self-pick-up store form in indirect delivery mode and combined delivery mode. Then, we assume that the alternative delivery mode set is $S = \{S_1, S_2, S_3, S_4, S_5, S_6, S_7\}$, where S_1 denotes home delivery mode, S_2 denotes Self-pick-up locker form, S_3 denotes Cooperation form, S_4 denotes Self-pick-up store form, $S_5 = \{S_{5a}, S_{5b}\}$ denotes Combined delivery model which consists of home delivery mode and Self-pick-up locker form, and S_{5a} denotes the home delivery mode in S_5 mode, S_{5b} denotes the Self-pick-up locker form in indirect delivery mode in S_5 mode. Similarly, $S_6 = \{S_{6a}, S_{6b}\}$ denotes the Combined delivery model which is consisted of home delivery mode S_{6a} and Cooperation form S_{6b} with convenience store in indirect delivery mode, $S_7 = \{S_{7a}, S_{7b}\}$ denotes Combined delivery mode which is consisted of the home delivery mode S_{7a} and Self-pick-up store form S_{7b} in indirect delivery mode.

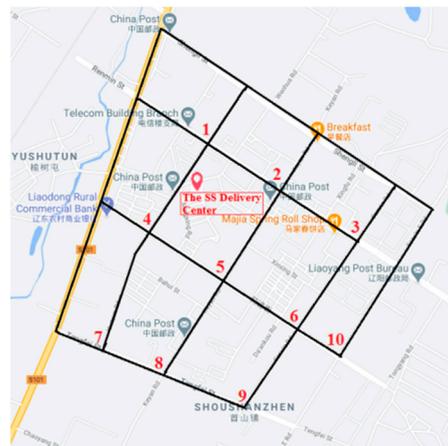


Figure 2. The last mile delivery areas of SS delivery center.

We assume that the attribute number each alternative is $N = 5$, and the attribute value set is $a_k = \{a_{k1}, a_{k2}, a_{k3}, a_{k4}, a_{k5}\}$, where a_{k1} denotes self-pick-up distance, a_{k2} denotes parcel security, a_{k3} denotes pick-up time window, a_{k4} denotes value-added service, and a_{k5} denotes service quality. Among them, the combined delivery mode is a pairwise combination of the home delivery mode and other indirect delivery modes, and the attribute importance value consists of the value for the two delivery modes in the combination.

7.1. Customer Utility Analysis

First, we conduct a questionnaire survey by the simple random sampling method. To obtain the more targeted and reliable data, we select the objective survey community within the delivery scope of the SS delivery center.

In the survey, we collected 362 questionnaires where 319 questionnaires were valid. Through the analysis of the valid questionnaire data by SPSS, we find that, from the perspective of gender, the proportion of males is 43.37% and that of females is 56.63%. From the perspective of age structure, the proportion of survey respondents aged between 18 and 50 is 99.23%. From the perspective of occupation, the proportion of office workers is 71.93%, and they are mainly online shoppers. From the above analysis, we find that the survey results are consistent with the characteristics of the customer groups in the SS delivery center, so the survey results are available [22].

Here, SPSS is used to analyze the importance score of short pick-up distance, high parcel security, flexible pick-up window time, high value-added service and high service quality. According to the practical situation of AA Express, we can subdivide the customer group into two types by optimal cluster number method proposed by Zhou et al. [36]. Obviously, the clustering number is 2. After repeated experiments, the number of iterations is set to 10. Therefore, for the total number of market segments is $I = 2$, the result of market segment set $I = \{I_1, I_2\}$ can be determined as shown in Table 9. Customers in the delivery area can also be divided into two types, customers of market type I_1 prefer service quality,

and the proportion is 29.73%. Customers of market type I_2 prefer to self-pick-up, and the proportion is 70.22%. Customers of both market types pay more attention to the security of parcels, which is also the basis of their satisfaction with the delivery service. According to the results of the questionnaire survey, statistics are made on the acceptance of the attribute level values of the logistics service modes for last mile delivery for customers of both market types as shown in Table 10.

Table 9. Attribute importance score in each market segment.

| I | a_{k1} | a_{k2} | a_{k3} | a_{k4} | a_{k5} | Percentage | Number |
|-------|----------|----------|----------|----------|----------|------------|--------|
| I_1 | 3 | 5 | 3 | 4 | 4 | 29.73% | 95 |
| I_2 | 4 | 4 | 5 | 3 | 3 | 70.22% | 224 |

Table 10. Score of acceptance degree of delivery service attribute for customers of two market segment.

| a_k | Level Description | Score of Customers in Market Segment I_1 | Score of Customers in Market Segment I_2 |
|----------|-------------------|--|--|
| a_{k1} | 0 km | 8.26 | 8.46 |
| | 0.25 km | 7.39 | 7.04 |
| | 0.5 km | 6.11 | 5.16 |
| a_{k2} | high | 8.63 | 8.39 |
| | medium | 6.29 | 6.39 |
| | low | 2.74 | 3.58 |
| a_{k3} | 2 h | 6.22 | 4.12 |
| | 10 h | 7.55 | 6.63 |
| | 12 h | 7.65 | 7.11 |
| a_{k4} | 24 h | 7.89 | 7.56 |
| | yes | 8.54 | 7.74 |
| | no | 3.39 | 6.84 |
| a_{k5} | high | 8.58 | 8.26 |
| | medium | 5.56 | 6.86 |
| | low | 3.63 | 5.25 |

The customer importance degree values for AA Express in market segments I_1 and I_2 are $w'_1 = 0.3$ and $w'_2 = 0.7$. From Table 9, we can obtain weighted value sets with respect to a_{kn} are $w_1 = \{0.6, 1, 0.6, 0.8, 0.8\}$ of market segment I_1 and $w_2 = \{0.8, 0.8, 1, 0.6, 0.6\}$ of market segment I_2 , respectively. From Table 10, we can determine the score Q_{ikn} of a_{kn} for customers in the i th market segment. By Equations (1)–(3), we can calculate the customer utilities of each market segment and the whole market for alternative logistics service mode or last mile delivery.

For home delivery mode, the customer utility calculation is conducted as follows:

$$V_{11} = \sum_{n=1}^5 w_{1n} Q_{11n} = 0.6 \times 8.26 + 1 \times 8.63 + 0.6 \times 6.22 + 0.8 \times 8.54 + 0.8 \times 5.56 = 28.60$$

$$V_{21} = \sum_{n=1}^5 w_{2n} Q_{21n} = 0.8 \times 8.46 + 0.8 \times 8.39 + 1 \times 4.12 + 0.6 \times 7.74 + 0.6 \times 6.86 = 26.36$$

$$V'_1 = \sum_{i=1}^2 w'_i V_{i1} = 0.3 \times 28.60 + 0.7 \times 26.36 = 27.03$$

Similarly, we can obtain: $V_{12} = 24.19$, $V_{13} = 20.93$, $V_{14} = 30.52$, $V_{15} = 28.6$, $V_{16} = 28.6$, $V_{17} = 30.52$, $V_{22} = 26.62$, $V_{23} = 25.11$, $V_{24} = 27.07$, $V_{25} = 26.62$, $V_{26} = 26.36$, $V_{27} = 27.07$, $V'_2 = 25.89$, $V'_3 = 23.86$, $V'_4 = 28.11$.

As the two market segments are equally important to the AA Express, we consider that the weight values of the customers in two market segments are 0.5. In the combined delivery mode, we can calculate the total customer utility according to the customer utility and customer importance degree value of each market segment. We can obtain $V'_5 = 0.5 \times V_{11} + 0.5 \times V_{22} = 0.5 \times 28.6 + 0.5 \times 26.62 = 27.61$. Similarly, we can obtain $V'_6 = 26.86$ and $V'_7 = 27.84$.

7.2. Delivery Service Cost Analysis

7.2.1. Customer Selection Probability Calculation

By the calculated customer utility and Equation (5), the total customer selection probability of each alternative logistics service mode for last mile delivery can be calculated, i.e., $P'_1 = 10.89\%$, $P'_2 = 3.48\%$, $P'_3 = 0.46\%$, $P'_4 = 32.06\%$, $P'_5 = 19.45\%$, $P'_6 = 9.19\%$ and $P'_7 = 24.47\%$. Then, we can obtain $P'_{5a} = 75.77\%$, $P'_{5b} = 24.23\%$; $P'_{6a} = 95.97\%$, $P'_{6b} = 4.03\%$; $P'_{7a} = 25.35\%$ and $P'_{7b} = 74.65\%$.

7.2.2. Delivery Quantity Calculation

By analyzing the historical data of 10 delivery areas, we can obtain the corresponding daily delivery data as shown in Table 11. It can be seen from the variation trend of daily delivery quantity with time that the daily delivery quantity increases year by year, we can use SPSS to predict daily delivery quantity. According to the four models in Table 2, we can conduct the variance analysis of daily delivery quantity, and determine the appropriate model, then we can further predict the daily delivery quantity of each delivery service area in 2020.

Table 11. The daily delivery quantity in each area for past five years and for 2020.

| Q | 2015 | 2016 | 2017 | 2018 | 2019 | Model | b_0 | b_1 | b_2 | 2020 |
|-----------------|------|------|------|------|------|----------------|-------|------------|-------|------|
| Q ₁ | 28 | 40 | 53 | 80 | 106 | S _s | −680 | −1,362,458 | 0 | 150 |
| Q ₂ | 13 | 20 | 25 | 36 | 51 | S _s | −673 | −1,348,623 | 0 | 70 |
| Q ₃ | 30 | 40 | 53 | 87 | 116 | G _r | −698 | 0.348 | 0 | 164 |
| Q ₄ | 28 | 35 | 56 | 82 | 110 | G _r | −719 | 0.359 | 0 | 160 |
| Q ₅ | 30 | 41 | 55 | 85 | 119 | G _r | −698 | 0.348 | 0 | 166 |
| Q ₆ | 24 | 37 | 46 | 69 | 95 | S _s | 684 | −1,370,265 | 0 | 133 |
| Q ₇ | 41 | 56 | 80 | 126 | 161 | S _s | 719 | −1,440,003 | 0 | 237 |
| Q ₈ | 31 | 43 | 57 | 88 | 121 | S _s | 697 | −1,396,650 | 0 | 175 |
| Q ₉ | 15 | 22 | 30 | 43 | 62 | G _r | −704 | 0.351 | 0 | 87 |
| Q ₁₀ | 21 | 29 | 40 | 60 | 84 | G _r | −701 | 0.350 | 0 | 118 |

In the following, we take the first delivery area as an example, and predict the daily delivery quantity Q_1 . By fitting the data of Q_1 in Table 11, we can obtain the results as shown in Table 12. For all prediction models shown in Table 12, we take the time (year) as the independent variable and Q_1 as the dependent variable. According to the variance analysis results by SPSS, we know that R^2 of model P_o , model S_s and model G_r are 0.997, respectively. The fitting degrees are very high, and the probabilities are all less than the entry probability 0.05. It is necessary to note that the F value of model S_s is 984.497, which is the highest among all models. Therefore, we use model S_s to predict Q_1 , and obtain that $Q_1 = 150$ parcels. Similarly, the daily delivery quantities of other delivery areas in 2020 can be predicted using the same method, and the results are shown in Table 11. By the calculated customer selection probability, calculated delivery quantities of 10 delivery areas and Equation (8), we can determine the daily delivery quantities of different logistics service modes in each delivery service area as shown in Table 13. Furthermore, the daily delivery quantity of delivery areas of the SS delivery center is 1460 parcels.

Table 12. Fitting model data for Q_1 .

| Model | Model Statistics | | | | | Parameter Evaluation | | |
|----------------|------------------|---------|--------|--------|-------|----------------------|----------------|-------|
| | R^2 | F | df_1 | df_2 | sig | b_0 | b_1 | b_2 |
| Q _u | 0.966 | 84.014 | 1 | 3 | 0.003 | −19,686.658 | 0.000 | 0.005 |
| P _o | 0.997 | 983.615 | 1 | 3 | 0.000 | 0.000 | 676.157 | |
| S _s | 0.997 | 984.497 | 1 | 3 | 0.000 | 680.166 | −1,362,458.192 | |
| G _r | 0.997 | 982.678 | 1 | 3 | 0.000 | −672.149 | 0.336 | |

Table 13. The daily delivery quantities of alternative logistics service modes in each area.

| Q | S ₁ ~S ₄ | S _{5a} | S _{5b} | S _{6a} | S _{6b} | S _{7a} | S _{7b} |
|-----------------|--------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Q ₁ | 150 | 114 | 36 | 144 | 6 | 38 | 112 |
| Q ₂ | 70 | 53 | 17 | 67 | 3 | 18 | 52 |
| Q ₃ | 164 | 124 | 40 | 157 | 7 | 42 | 122 |
| Q ₄ | 160 | 121 | 39 | 154 | 6 | 41 | 119 |
| Q ₅ | 166 | 126 | 40 | 159 | 7 | 42 | 124 |
| Q ₆ | 133 | 101 | 32 | 128 | 5 | 34 | 99 |
| Q ₇ | 237 | 180 | 57 | 227 | 10 | 60 | 177 |
| Q ₈ | 175 | 133 | 42 | 168 | 7 | 44 | 131 |
| Q ₉ | 87 | 66 | 21 | 83 | 4 | 22 | 65 |
| Q ₁₀ | 118 | 89 | 29 | 113 | 5 | 30 | 88 |
| Q | 1460 | 1106 | 354 | 1401 | 59 | 370 | 1090 |

7.2.3. Delivery Service Cost Analysis

Through the survey of AA Express and deliverymen, we can determine the relevant cost of each alternative logistics service mode for SS delivery center as shown in Table 14. The daily working time of the SS delivery center is from 8:00 to 18:00, and the delivery time of each deliveryman is 8 h, and the delivery time window service is not provided. From Table 14, for mode S₁, the electric tricycle can be used to deliver parcels, it can load and deliver 200 parcels, and the average time for each parcel delivery is 3 min. Therefore, we know that the daily delivery capacity of a deliveryman is 160 parcels. Hence, for 1460 parcels, 10 deliverymen are needed, and each deliveryman average daily delivers 146 parcels.

For modes S₂, S₃ and S₄, the minivans can be used to delivery parcels, each of which can load and deliver 800 parcels, and the average time of each parcel delivery is 0.3 min. Therefore, the daily delivery capacity of a deliveryman is 1600 parcels. Given the limitation of delivery time and delivery speed, two deliverymen are needed for 1460 parcels delivery, each deliveryman delivers 730 parcels per day.

From Table 13, we know that the delivery quantities for self-pick-up form are very low for modes S₅ and S₆, and they are far less than the load capacity of minivans, so the electric tricycles can be used to deliver parcels. For mode S₇, the delivery quantity of self-pick-up form is very high, whereas the delivery quantity of home delivery mode is 370 parcels, so the minivan can be used to deliver parcels. As 370 parcels are larger than the daily delivery capacity of two deliverymen, the delivery quantity is evenly distributed to three deliverymen, and each deliveryman delivers 487 parcels per day.

According to the daily delivery quantity of the SS delivery center and the cost parameter values, we can calculate the daily delivery service cost of each alternative logistics service mode $S = \{S_1, S_2, S_3, S_4, S_5, S_6, S_7\}$, i.e., $C_D(Q) = 1766.99$, $C_L(Q) = 1511.51$, $C_O(Q) = 1358.45$, $C_S(Q) = 2837.81$, $C_H(Q)_5 = 2197.75$, $C_H(Q)_6 = 1692.33$ and $C_H(Q)_7 = 3136.08$.

7.3. The Selection of Logistics Service Mode for Last Mile Delivery

According to above analysis, we can determine the decision index values of “utility-cost” two-dimensions of each alternative logistics service mode for last mile delivery as shown in Table 15. The corresponding coordinate values of the two dimensions are shown in Figure 3.

Table 14. The related cost of each alternative logistics service mode for SS delivery center.

| Parameter | Unit | S ₁ | S ₂ | S ₃ | S ₄ | S ₅ | S ₆ | S ₇ |
|------------------|---------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| SW | CNY | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| Q | Parcels | 1460 | 1460 | 1460 | 1460 | 1460 | 1460 | 1460 |
| Q _v | Parcels | 146 | 730 | 730 | 730 | 146 | 146 | 487 |
| DT | times | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| PC ₁ | CNY | 4500 | 50,000 | 50,000 | 50,000 | 4500 | 4500 | 50,000 |
| α ₁ | | 0.05 | 0.20 | 0.20 | 0.20 | 0.05 | 0.05 | 0.20 |
| L ₁ | Year | 4 | 10 | 10 | 10 | 4 | 4 | 10 |
| PC ₂ | CNY | 1700 | 1700 | 1700 | 1700 | 1700 | 1700 | 1700 |
| α ₂ | | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| L ₂ | Year | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| TW | CNY | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IM | CNY | 5 | 7 | 6 | 7 | 5 | 5 | 7 |
| PR | CNY | 1 | 0.3 | 0.3 | 0.3 | 1, 0.3 | 1, 0.3 | 1, 0.3 |
| ip | | 0.95 | 1 | 1 | 1 | 1 | 1 | 1 |
| e | CNY | 0.001 | 0.012 | 0.013 | 0.012 | 0.001 | 0.001 | 0.013 |
| v | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| win | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| z | CNY | 0.02 | 0 | 0.01 | 0 | 0.02 | 0.01 | 0.01 |
| r | | 0.05 | | | | | | |
| ht | Hour | 0.25 | | | | | | |
| lc | CNY | 5 | | | | | | |
| PC ₀ | CNY | | 280 | | | 280 | | |
| α ₀ | | | 0.20 | | | 0.20 | | |
| L ₀ | Year | | 5 | | | 5 | | |
| λ | | | 1.1 | | | 1.1 | | |
| LR | CNY | | 70 | | | 70 | | |
| σ ₁ | CNY | | | 0.5 | | | 0.5 | |
| n | Parcel | | 10 | | 10 | 10 | | 10 |
| SR | CNY | | | | 100 | | | 100 |
| PC' ₀ | CNY | | | | 4500 | | | 4500 |
| α' ₀ | | | | | 0.05 | | | 0.05 |
| L' ₀ | Year | | | | 5 | | | 5 |

Table 15. The decision index values for different logistics service mode for last mile delivery of AA Express.

| Dimension | S ₁ | S ₂ | S ₃ | S ₄ | S ₅ | S ₆ | S ₇ |
|-----------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| V | 27.03 | 25.89 | 23.86 | 28.11 | 27.61 | 26.86 | 27.84 |
| C | 1766.99 | 1511.51 | 1358.45 | 2837.81 | 2197.75 | 1692.33 | 3136.08 |

According to the two-dimensional matrix decision model of logistics service mode selection for last mile delivery in Section 6, we know that the optimal logistics service mode for last mile delivery in SS delivery center of AA Express is Combined delivery mode S₅ with home delivery mode and Self-pick-up locker form in indirect delivery mode, this is because the delivery service cost is lower and customer utility is higher in region, i.e., mode S₅ has both advantages of delivery service cost and customer utility.

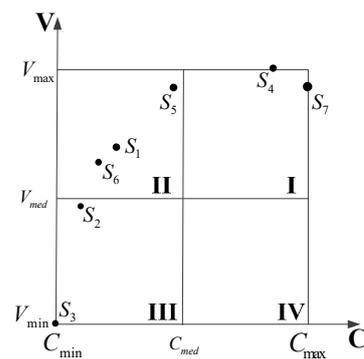


Figure 3. Logistics service mode selection for last mile delivery for SS delivery center of AA Express.

8. Conclusions

In this study, we focus on the method for logistics service mode selection for last mile delivery considering customer utility and delivery service cost, and some important conclusions are summarized. First, we propose the combined logistics service mode for last mile delivery, and construct the calculation models for customer utility and delivery service cost in the combined logistics service mode. Our work provides more selections for express enterprises in their logistics service mode selection decision for last mile delivery. Secondly, we pay attention to the customer utility and analyze its impact on customer selection behavior in logistics service mode selection for last mile delivery. Specifically, we segment the market through customer demand survey, and propose the calculation methods of customer utility and customer selection probability based on the utility theory and the discrete choice model. The consideration of the customer utility increases the applicability and practicability of logistics service mode selection for last mile delivery. Thirdly, we propose a prediction method for delivery service quantity based on the combination of time series and customer selection probability, it provides a reasonable basis for the calculation of delivery service cost.

For the further research, we will focus on the impact of the competition in the market on the logistics service mode selection for last mile delivery, and study the logistics service mode selection for last mile delivery considering the rival's logistics service mode for last mile delivery. In addition, some new delivery service tools are emerging, such as UAV and unmanned vehicle, the new tools will change the cost and potential logistics service mode for last mile delivery. In the further research, we are considering new delivery service tools and will pay attention to the logistics service mode selection for last mile delivery.

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