The Logistics Service Mode Selection for Last Mile Delivery Considering Delivery Service Cost and Capability

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Abstract: The last mile delivery service is an important part in the logistics service process of express enterprises. How to select a suitable logistics service mode for last mile delivery to maximize the delivery service capacity and minimize delivery service cost is a noteworthy problem, but studies on this problem are still lacking. In this paper, we first analyze three potential logistics service modes for last mile delivery, i.e., self-run mode, outsourcing mode, and alliance mode, and then propose a selection framework of logistics service mode for last mile delivery based on a two-dimensional matrix decision model according to the two dimensions of delivery service cost advantage and delivery service capability advantage. Next, we give the calculation formulas for the delivery service cost and delivery service capability. Furthermore, we propose a method for logistics service mode selection for last mile delivery according to delivery service costs and delivery service capabilities of three potential logistics service mode. Finally, we show the feasibility and effectiveness of the proposed method by a case analysis.

Keywords: logistics service mode; last mile delivery; delivery service cost; delivery service capability; mode selection

1. Introduction

With the development of Internet consumption, China’s express industry has been growing at an annual rate of nearly 50 percent for 12 consecutive years [1]. In 2019, China’s express enterprises completed the delivery service of more than 63 billion pieces, and the average number of delivery pieces per capita was 45. Especially since the outbreak of novel coronavirus pneumonia in 2020, the express industry has developed even more rapidly. China’s express delivery volume has been the top of the world for six consecutive years since 2014 [2]. The rapid development of the express delivery industry has caused a shortage of delivery employees, and further caused the reduction of the delivery service level. In this background, for the labor-intensive express industry, how to solve the last mile delivery problem at the end of logistics service is an extremely urgent problem.

Last mile delivery service refers to the delivery process of delivering products from the delivery service station to customers and realizing door-to-door delivery service when the products purchased by customers arrive at the delivery station [3], it is also an important part in the logistics service process of express enterprises [4]. Last mile delivery service has the characteristics of high delivery time requirements, small batches, multiple batches, unstable circulation, and high delivery service...
cost [5]. In reality, for example, for a new last mile delivery service branch in the secondary delivery center of SH Street in Shenyang City of YD Express, the logistics service mode is directly related to the profit of this branch. To implement the profit expectation, how to select the suitable logistics service mode for last mile delivery is a noteworthy research topic from the perspective of express enterprises considering the requirements of low delivery service cost and high delivery service capability.

In recent years, some relevant results on the selection of logistics service mode for last mile delivery can be seen. For the research on the concept and characteristics of the logistics service mode for last mile delivery, some scholars have obtained some results [6–8]. For example, Lim et al. [6] found that the last mile delivery service is a part of supply chain with high cost and low operation efficiency, and showed that the suitable logistics service mode can reduce costs, improve operation efficiency and further optimize the delivery process. Zheng [8] proposed the concepts of self-run delivery, third-party delivery, and mixed delivery for last mile delivery, and analyzed the characteristics and advantages of these three modes.

For the research on the logistics service mode selection method [9–13], for example, Ballou [9] thought that the express enterprises need to consider two key factors in the logistics service mode decision-making process—the importance of logistics to enterprise success and the ability of enterprise logistics operation. On this basis, he innovatively established a two-dimensional decision-making model based on the qualitative analysis method, and proposed Ballou model theory and improved the theoretical system of logistics service mode selection. Peng [10] proposed a selection method based on analytic hierarchy process (AHP) to evaluate and select logistics outsourcing service providers and designed a corresponding evaluation index system. Ji [11] established a delivery service mode selection model based on the combination of gray analytic hierarchy process (GAHP) and grey correlation degree method using mathematical modeling method. The most suitable delivery service mode can be determined according to the weight of each index calculated by GAHP method and the superiority of each alternative with respect to different attributes evaluated by grey correlation degree method. In addition, Holdorf and Haasis [12] used the empirical analysis method to develop the customer preference model on the logistics service mode of the last mile delivery, and found that express enterprises can improve their competitive advantage by analyzing customers’ preference. Thirumalai and Sinha [13] focused on the customer satisfaction evaluation in the delivery service process, and found that customer satisfaction is related to the customers’ expectation of the delivery service.

In addition, there are some related research results on the last mile outsourcing, crowdsourcing, and vehicle routing problem [14–17]. For example, Kitjacharoenchai et al. [14] studied the drone routing and scheduling in last mile delivery and developed a new routing model considering a synchronized truck–drone operation, showing the delivery time improvement of the proposed model. Huang and Ardiansyah [15] thought that crowdsourced delivery offers greater flexibility and requires less capital investment than traditional outsourcing approaches, and developed a decision model for last mile delivery planning with crowdsourcing integration. Alcaraz et al. [16] focused on the rich vehicle routing problem with last mile outsourcing decisions, showing the impact and the cost-effectiveness of the outsourcing attributes. Goswami et al. [17] examined the freight performance of third-party logistics providers within the automotive industry in India, and found that effective transport planning and distribution network design can be a source of sustainable supply chain performance.

In reality, in the process of logistics service mode selection for last mile delivery, express enterprises need to pay attention to some impact factors [18–27]. For example, Jing [18] focused on the impacts of vehicle matching degree and transportation factors on the delivery service cost, Koetse et al. [19] focused on the impacts of extreme weather and natural disasters, Urzua-Morales et al. [20] proposed a flexible freight transport solution that improves delivery service efficiency and minimizes the environmental impact of the atmospheric pollution. Nemoto [21] focused on information technology factors and show that the application of ICT can reduce the complexity of logistics operations and improve the operation efficiency. Boyer et al. [22] paid attention to the factor of customer density and found that increase of customer density can reduce the delivery distance and further reduce the delivery service
cost. Meanwhile, Schramm-Kleinnet et al. [23] and Jane et al. [24] incorporated the cost indexes into the evaluation system. Ko et al. [25] proposed a last mile delivery time function considering the market density based on a collaboration model with the objective of the cost minimization, and showed that the method can improve delivery service efficiency. Gevaers et al. [26] summarized the impact factors of the last mile delivery service cost, and modeled the last mile delivery service cost considering the following five factors: customer service level, safety and logistics service mode, geographical area and market density, delivery vehicles and technology, and environment. Zheng et al. [27] proposed an evaluation index system of logistics service quality, the system includes the following factors: time index for reflecting delivery speed, personnel communication, order completion, error processing, flexibility and convenience, and demonstration of the impact of these factors on customer service in logistics service.

The existing research results have made great contributions to the study on the logistics service operations and the indexes of logistics service mode selection. However, these results do not involve logistics service mode selection for last mile delivery and the specific indexes on the delivery service cost reduction and delivery service capability improvement, which are the key dimensions of the logistics service mode selection for last mile delivery of express enterprises. Obviously, the existing research results cannot be used to solve the logistics service mode selection for last mile delivery considering above two dimensions. In reality, for a new last mile delivery service branch, the logistics service mode is critical in the implementation of its profit expectation, and logistics service mode selection needs to consider the impacts of these two dimensions. To bridge the gaps of theoretical research results and practice, the logistics service mode selection for last mile delivery of express enterprise was studied, considering the two dimensions of delivery service cost reduction and delivery service capability improvement. Through this research, the deficiencies or limitations of the existing research can be made up.

The purpose of this paper is to propose a new method for logistics service mode selection for last mile delivery based on the two dimensions of delivery service cost and delivery service capability. For the three potential logistics service modes for last mile delivery for express enterprises, i.e., self-run mode, outsourcing mode and alliance mode, the corresponding delivery service cost and the delivery service capability for each mode are analyzed by division of the service process of last mile delivery according to the characteristics of different delivery service processes. Furthermore, the calculation methods of delivery service cost and delivery service capability are given, respectively. On this basis, the optimal mode for last mile delivery based on the two dimensions of delivery service cost and delivery service capability are given.

The contributions of our study have three aspects. First, we propose the conception of delivery service cost advantage for last mile delivery and provide a feasible way to analyze the involved costs in last mile delivery and the calculation equations of these involved costs. Secondly, we propose the conception of delivery service capacity advantage for last mile delivery and show the main components of delivery service capacity advantage and calculation equations of these involved components. Thirdly, we comprehensively analyze the impacts of the delivery service cost advantage and delivery service capability advantage, and develop a logistics service mode selection method for last mile delivery considering delivery service cost and capability based on the Ballon model.

The remainder of the paper is arranged as follows: Section 2 designs the framework of the logistics service mode selection for last mile delivery; Section 3 gives the analysis and calculation method of delivery service cost. In Section 4, the analysis and calculation method of delivery service capability are given. Section 5 provides the method for logistics service mode selection for last mile delivery based on the two dimensions of delivery service cost and delivery service capability. Section 6 gives a case analysis. Finally, Section 7 summarizes the main conclusions of this paper and shows the further research work.

2. The Framework of Mode Selection

The last mile delivery service process mainly contains basic delivery (i.e., first-time delivery and second-time delivery), reverse delivery, and time-limited delivery. In addition, the last mile delivery
service process involves some management links, such as the construction management of delivery stations, daily event management and special event management. Although these management links do not directly participate in the delivery process, they provide basic guarantee for the normal operation of the whole last mile delivery service.

In reality, there are three potential logistics service modes for last mile delivery of express enterprise, i.e., self-run mode, outsourcing mode, and alliance mode.

Self-run mode refers to a delivery service mode in which an express enterprise purchases equipment to independently build delivery-related facilities and forms delivery service teams. In this mode, the express enterprise directly interacts with the end customers and organizes and implements the last mile delivery service. Usually, when the delivery service market share of the express enterprise in a specific region is relatively high, or the delivery service requirements of customers in the region are relatively high, express enterprises will adopt the self-run mode. Self-run mode has the advantages of obtaining the demand information in time by direct interaction with end customers, improving delivery service efficiency and reducing delivery service costs, but it also has the disadvantages of easy impact of delivery service-related factors on the main business, coverage area limitation of delivery services, and difficulty in forming specialized delivery operations.

Outsourcing mode refers to a delivery service mode in which an express enterprise selects one or more professional other express enterprises to share the delivery service, thus realizing delivery service and real feedback of delivery information. The mode has the advantages of less fixed capital investment, fast capital turnover, low average cost, and wide delivery coverage, but it also has the disadvantages of poor standardization, low delivery service quality, and uncontrollable delivery service links.

Alliance mode refers to a delivery service mode in which multiple express enterprises cooperate to form a delivery service alliance with shared risks, profits, losses, and complementary resources. The model has the advantages of scale effect, low delivery service cost, high sharing rate of delivery service resources, high use efficiency of delivery resources, and large delivery coverage, but it also has the disadvantages of low personalized service level and uncoordinated management between enterprises or within enterprises.

There are many factors that can affect the logistics service mode selection for last mile delivery, but it is not difficult to find out through in-depth research on the Ballou model [9] that there are two key factors that mainly affect the logistics service mode selection decision-making for last mile delivery in the model. The two factors are the importance of logistics to the success of enterprises and the logistics operation ability of enterprises. Decision makers can select the optimal logistics service mode for last mile delivery according to their own conditions.

The last mile delivery service is the biggest bottleneck of delivery service performance improvement and plays an important role in the success of enterprises. Ballou’s two-dimensional decision matrix model provides the decision basis for the logistics service mode selection for last mile delivery, and tries to achieve the mutual balance between the enterprise management strategies and the delivery service system. However, in the model establishment process, the most concerning factor of the enterprise is ignored, i.e., the management cost, which causes great limitations in the actual application of the model.

It is necessary to point out that, the delivery service is the main business of express enterprises, and delivery service capability plays a vital role in the development of express enterprises. Given that the last mile delivery is the key part of delivery service with the characteristics of high consumption cost and low operation efficiency [28], how to improve the delivery service capability and select the optimal logistics service mode for last mile delivery is an important topic with a wide range of practical background and practical significance [29–31].

This paper focused on and analyzed two important factors that are closely related to the selection of logistics service mode for last mile delivery. One is delivery service capability advantage (DSCA), which is mainly reflected in the advantages of express enterprises in response speed, punctuality, and reliability in the process from order processing to product delivery. The other is delivery service
cost advantage (DCA), which is mainly reflected in the cost advantage of express enterprises in the delivery links of loading and unloading, handling, storage, and transportation.

Obviously, if an express enterprise pays attention only to improving the delivery service capability without considering the reduction of delivery service costs, then the enterprise may suffer an operational loss or may not be able to maintain sustainable operation. If an express enterprise pays attention only to the reduction of delivery service costs without considering the improvement of delivery service capability, then the customer satisfaction of the enterprise may drop significantly, and it will further cause the loss of a large number of customers and even a business crisis. Therefore, it is very necessary to simultaneously consider both DSCA and DCA in logistics service mode selection for last mile delivery. It is necessary to point out that, since the regional last mile delivery market is usually not competitive, we assumed that consumers are completely satisfied with the delivery service.

Here, we considered DSCA and DCA as two dimensions in logistics service mode selection for last mile delivery, and further constructed the framework of logistics service mode selection for last mile delivery based on a two-dimensional matrix decision model, as shown in Figure 1. In Figure 1, the horizontal axis denotes the DCA dimension and the vertical axis denotes the DSCA dimension. We considered that the line of “market average” in the two-dimensional matrix decision model as the dividing line, and then the four regions can be formed accordingly, i.e., Regions I, II, III, and IV. For a certain express enterprise, the position in the two-dimensional matrix decision model will imply its suitable logistics service mode for last mile delivery.

![Two-dimensional matrix decision model for logistics service mode selection for last mile delivery.](image)

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

The four regions in the two-dimensional matrix decision model have different meanings. In the following, we provide a brief illustration.

Region I: The express enterprise in this region has strong advantages in delivery service cost and delivery service capability. The enterprise can effectively meet the market demand alone and trend to select the self-run mode for last mile delivery.

Region II: The express enterprise in this region has weak advantage in delivery service cost, but has strong advantage in delivery service capability. The enterprise can effectively meet the market demand and trend to select the alliance mode. It is necessary to point out that the enterprise will be the leader in alliance mode.

Region III: The express enterprise in this region has weak advantages in both delivery service cost and delivery service capability. The enterprise cannot meet the market demand well, and thus trends to select the outsourcing mode.

Region IV: The express enterprise in this region has a strong advantage in delivery service cost, but has weak advantage in delivery service capability. The enterprise can also meet the market demand and trends to select the alliance mode. It necessary to point out that, to seek a beneficial
operation, an enterprise needs to form an alliance with an enterprise with a strong advantage in delivery service capability.

3. Delivery Service Cost

For the convenience of following analysis, we first provide the notations of symbols involved in delivery service cost, as shown in Table 1. The delivery service cost for last mile mainly contains two aspects: labor cost and transportation delivery service cost. According to economic theory, the labor cost can be converted into the corresponding time cost, and the transportation delivery service cost can be converted into the corresponding distance cost. Therefore, the standard cost function of last mile delivery can be written as: \( C_A = Tt_c + Dd + Z \) [32]. In addition, we considered that the customer adopts the face-to-face sign-in mode in the first-time and second-time delivery services, and also considered that the time-limited delivery service is constrained by bilateral time windows, and that all pieces fit a unified time window width.

1. About the “face to face sign-in mode for first and second delivery”, this means that customers need to sign for the delivered pieces face to face with the deliveryman in both first-time delivery and second-time delivery. There are many terminal receiving modes for customers in the last mile delivery, and they mainly contain face-to-face sign-in mode, receiving box mode, and collection point mode. In our study, we assumed that the customers use the face-to-face sign-in mode.

2. About the “constrained by bilateral time windows”, this means that customers can accept the delivered pieces only in the specified time interval. In time-limited delivery service, the time window constraints usually contain unilateral time window constraints and bilateral time window constraints. In our study, we mainly considered bilateral time window constraints.

3. About the “unified time window width”, this means that the specified time interval is the same and unified for all pieces accepted by customers. In the time-limited delivery service, since the time window constraint is an additional service and time window constraint will cause the consumption of human and financial resources, we assumed that all pieces are in the unified time window width.

### Table 1. Notation of symbols involved in delivery service cost.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Description</th>
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<th>Description</th>
</tr>
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<tbody>
<tr>
<td>( C_B )</td>
<td>The basic delivery service cost;</td>
<td>( Z )</td>
<td>The additional costs that are not related to time and distance;</td>
</tr>
<tr>
<td>( C_1^B )</td>
<td>The first-time delivery service cost;</td>
<td>( u )</td>
<td>The additional labor cost coefficient, which is used to describe the labor cost incurred during abnormal working hours;</td>
</tr>
<tr>
<td>( C_2^B )</td>
<td>The second-time delivery service cost;</td>
<td>( D )</td>
<td>The delivery distance;</td>
</tr>
<tr>
<td>( C_R )</td>
<td>The reverse delivery service cost;</td>
<td>( d )</td>
<td>The unit distance cost;</td>
</tr>
<tr>
<td>( C_1^R )</td>
<td>The basic cost of reverse delivery;</td>
<td>( v )</td>
<td>The vehicle type coefficient, which is used to describe the impact of vehicle types on basic delivery service costs;</td>
</tr>
<tr>
<td>( C_2^R )</td>
<td>The additional processing cost;</td>
<td>( n_t )</td>
<td>The number of pieces delivered at T time;</td>
</tr>
<tr>
<td>( C_T )</td>
<td>The time-limited delivery service cost;</td>
<td>( n_a )</td>
<td>The average daily delivery quantity (actual market demand);</td>
</tr>
<tr>
<td>( C_F )</td>
<td>The annual apportioned construction cost;</td>
<td>( w )</td>
<td>The time window coefficient, which is used to describe the change in the number of delivered pieces for each deliveryman due to the customer’s time constraints;</td>
</tr>
<tr>
<td>( C_M )</td>
<td>The annual management cost;</td>
<td>( p_f )</td>
<td>The success probability of first-time delivery;</td>
</tr>
<tr>
<td>( C_E )</td>
<td>The annual additional special processing cost;</td>
<td>( p_r )</td>
<td>The probability of reverse delivery;</td>
</tr>
<tr>
<td>( C'_M )</td>
<td>The daily management cost;</td>
<td>( c_r )</td>
<td>The unit time processing cost for reverse delivery;</td>
</tr>
<tr>
<td>( C'_E )</td>
<td>The daily additional special processing cost;</td>
<td>( t_b )</td>
<td>The processing time of each piece in reverse delivery;</td>
</tr>
<tr>
<td>( C_S )</td>
<td>The cost of the opportunity loss;</td>
<td>( C_i )</td>
<td>The total delivery service cost of each piece under mode ( i );</td>
</tr>
<tr>
<td>( T )</td>
<td>The delivery arrival time;</td>
<td>( C_A )</td>
<td>The total delivery service cost;</td>
</tr>
<tr>
<td>( t_c )</td>
<td>The unit time cost;</td>
<td>( S )</td>
<td>The average delivery service cost of each piece.</td>
</tr>
</tbody>
</table>
In the following, we first give the analysis of delivery service cost for last mile, and then give the total cost analysis of each logistics service mode.

### 3.1. Analysis of Delivery Service Cost

#### 3.1.1. Analysis of the Basic Delivery Service Cost

Generally, the basic delivery service cost $C_B$ can be divided into first-time delivery service cost $C^1_B$ and second-time delivery service cost $C^2_B$. For a single standard volume weight piece, $C^1_B$ and $C^2_B$ are the same. Given that the number of pieces in second-time delivery service is less than or equal to the ones in first-time delivery service, the total cost of second-time delivery service is usually not greater than the one of first-time delivery service.

According to the total delivery service cost $C_A$, the additional labor cost coefficient $u$, the vehicle type coefficient $v$ [26], and the time window coefficient $w$ [22], the function of first-time delivery service cost can be determined, i.e.,

$$C^1_B = \frac{T_{1u} + Ddv}{n_t/w}n_a.$$  

(1)

According to the first-time delivery service cost $C^1_B$ and the success probability of first-time delivery $p_f$, the function of second-time delivery service cost $C^2_B$ can be determined, i.e.,

$$C^2_B = \frac{T_{1u} + Ddv}{n_t/w}n_a(1 - p_f).$$  

(2)

Based on the above analysis, the function of basic delivery service cost $C_B$ can be determined, i.e.,

$$C_B = C^1_B + C^2_B = \frac{T_{1u} + Ddv}{n_t/w}n_a + \frac{T_{1u} + Ddv}{n_t/w}n_a(1 - p_f).$$  

(3)

#### 3.1.2. Analysis of the Reverse Delivery Service Cost

The reverse delivery service cost $C_R$ mainly contains the basic cost $C^1_R$ of reverse delivery and the additional processing cost $C^2_R$. Generally, $C^1_R$ is the same as $C^1_B$, and some delivered pieces at the delivery station will be into the reverse delivery. Delivery service providers can determine the probability of reverse delivery $p_r$ according to previous reverse delivery data. The number of pieces $n_a(1 - p_f)$ that fail to be delivered in the first-time delivery will be in the reverse delivery. Therefore, the function of the basic cost of reverse delivery $C^1_R$ can be determined, i.e.,

$$C^1_R = \frac{T_{1u} + Ddv}{n_t/w}n_a(p_r + 1 - p_f).$$  

(4)

In addition, in the process of reverse delivery, additional processing cost $C^2_R$ usually occurs. Since the reasons that the pieces need to be in the reverse delivery are different, the processing cost of each piece in the reverse delivery may be also different. Generally, to determine the additional processing cost, it will be converted into the corresponding time cost. Specifically, the function of the additional processing cost $C^2_R$ can be written as

$$C^2_R = p_r n_a c_l h.$$  

(5)

On this basis, the function of the reverse delivery service cost $C_R$ can be determined, i.e.,

$$C_R = C^1_R + C^2_R = \frac{T_{1u} + Ddv}{n_t/w}n_a(p_r + 1 - p_f) + p_r n_a c_l h.$$  

(6)
3.1.3. Analysis of Time-Limited Delivery Service Cost

Since the delivery route and the delivery process may be uncertain, the time \( x_i \) when the \( i \)th piece arrives at the customer side is also uncertain. According to the constraint of soft time window condition [33,34], we considered the best delivery time window for arrival of the piece at the end customer side is \((e_i, l_i)\). If the piece arrives at the end customer side before the lower limited time point \( e_i \), the enterprise suffers the penalty cost \( h \) per unit time for the arrival in advance; if the piece arrives at the end customer side after the upper limited time-point \( l_i \), the enterprise suffers the penalty cost \( r \) per unit time for delayed arrival. Based on above analysis, the function of the penalty cost \( E(c_i) \) for each piece considering the constraint of the time window condition can be determined, i.e.,

\[
E(c_i) = h(e_i - x_i)^+ + r(x_i - l_i)^+.
\] (7)

We considered that if the arrival time \( x_i \) of the \( i \)th piece follows the distribution with probability density function \( f(x) \), the earliest delivery time for the time window is \( M \), and the latest delivery time is \( N \), then the penalty cost \( E(c_i) \) can be converted into the following form, i.e.,

\[
E(c_i) = \begin{cases} 
  h \int_M^x [(e-x)f(x)]dx, & M \leq x < a \\
  0, & a \leq x \leq b \\
  r \int_N^x [(x-l)f(x)]dx, & b < x \leq N 
\end{cases}
\] (8)

Furthermore, we considered that the number of pieces in the time window \((e_i, l_i)\) is \( Q_i \), so where \( \sum Q_i \leq Q_{sum} \), the cost function \( C_T \) of time-limited delivery service can be determined, i.e.,

\[
C_T = \sum_{i=1}^n Q_i E(c_i).
\] (9)

3.1.4. Analysis of Fixed Assets Construction Cost and Other Management Costs

The annual management cost \( C_M \) and annual additional special processing cost \( C_E \) are important and indispensable components of the operation cost for last mile delivery, but their proportions are relatively small, and they can be roughly estimated in actual operation.

We considered that the size index of the number of the delivery service stations is \( \alpha (0 < \alpha < 1) \), the actual capacity of the delivery service stations in construction is \( Q_0 \), the average minimum capacity of the delivery service stations in construction is \( Q_N \), and the construction cost for minimum capacity of the delivery service stations in construction is \( C^\alpha_f \). Therefore, for the construction of the delivery service station with capacity \( x \), the function of the fixed assets construction cost can be determined, i.e.,

\[
C_f^\alpha(Q_0) = \begin{cases} 
  C_f^0 + E_0(Q_0 - Q_N)^\alpha, & Q_0 > Q_N \\
  C_f^0, & Q_N \geq Q_0 > 0 \\
  0, & Q_0 = 0 
\end{cases}
\] (10)

where \( E_0 \) denotes the cost coefficient per unit capacity.

We considered that if the depreciation of infrastructure and equipment is over a period of \( L \) years, then we know that the annual apportioned construction cost is \( C_F = C_f^\alpha(Q_0)/L \). On that basis, the function of the construction cost of the infrastructures and the equipment can be determined, i.e.,

\[
C_F(Q_0) = \begin{cases} 
  C_f^0/L + (E_0/L)(Q_0 - Q_N)^\alpha, & Q_0 > Q_N \\
  C_f^0/L, & Q_N \geq Q_0 > 0 \\
  0, & Q_0 = 0 
\end{cases}
\] (11)

In addition to the above-mentioned explicit costs, the express enterprise also has implicit opportunity loss cost \( C_s \). When the delivery service capacity of an express enterprise is lower than
the actual market demand, the orders beyond the delivery service capacity will not be completed, which causes the occurrence of opportunity loss cost. Based on above analysis, the function of opportunity loss cost $C_S$ can be determined, i.e.,

$$C_S = S(n_a - Q_0), \quad n_a \geq Q_0. \quad (12)$$

It is necessary to point out that, the opportunity loss cost may not occur if the delivery service capacity of express enterprise is not lower than the actual market demand.

3.2. Total Cost Analysis of Each Logistics Service Mode

In real last mile delivery operation, the express enterprise needs to face an important problem, which is how to select the optimal logistics service mode for last mile delivery from the potential three modes.

For the self-run mode, the initial cost is very high because the delivery infrastructure investment is high. With the completion of infrastructure construction, the delivery service cost of each piece will increasingly decrease and the delivery service efficiency will be continuously improved.

For the outsourcing mode, the fixed infrastructure investment is less, but the service efficiency will be improved, and it could cover a larger delivery area. However, the delivery service links are difficult to control and the standardization is poor, and thus the quality of logistics service will be reduced. With the increase of the quantity of delivered pieces, the delivery service cost also increases accordingly.

For the alliance mode, the delivery service cost will be reduced because of economies of scale and the delivery route will be optimized in the whole delivery network. However, since the enterprises involved in the delivery are multiple and their management modes are diverse, the logistics service mode for last mile delivery must be standardized, which will cause the reduction of the delivery service level.

3.2.1. Self-Run Mode

Based on above analysis, the total cost $C_a$ for the self-run mode can be determined, i.e.,

$$C_a = C_B + C_E + C_F + C_M + C_T + C_S. \quad (13)$$

According to Equation (1) to Equation (12), $C_a$ can be converted into the following form, i.e.,

$$C_a = \begin{cases} \frac{T_{l,u} + D_{l,u}}{n_l/w} n_a + 2n_a(1 - p_f) \frac{T_{l,u} + D_{l,u}}{n_l/w} + C_M + C_E + S(n_a - Q_0) + \sum_{i=1}^{n} Q_i E(c_i) + C_F(Q_0); & n_a \geq Q_0 \\ + \frac{T_{l,u} + D_{l,u}}{n_l/w} n_a p_r + p_r n_a c_i + \sum_{i=1}^{n} Q_i E(c_i) + C_F(Q_0); & n_a < Q_0 \end{cases}. \quad (14)$$

It is necessary to note that if $n_a \geq Q_0$, the maximum quantity of delivered pieces in delivery service station is the actual operation $Q_0$, and the quantity beyond maximum quantity $Q_0$ will cause opportunity loss cost; if $n_a < Q_0$, the maximum quantity of delivery pieces in delivery service station is the actual market demand $n_a$, and opportunity loss cost will not occur.

3.2.2. Outsourcing Mode

In this mode, the express enterprise will not directly conduct the logistics service for last mile delivery, but entrust the third-party logistics service provider to operate the delivery service. The delivery service cost is positively related to the quantity of pieces $n$. Given that the express
enterprise needs to pay the third-party logistics service provider at price $\lambda$ for each delivered piece. Then, the total delivery service cost $C_b$ in outsourcing mode can be further determined, i.e.,

$$C_b = n\lambda.$$  

(15)

3.2.3. Alliance Mode

The total delivery service cost in alliance mode can be determined in the same way to the one in self-run mode as shown in Equation (13). Given that the average delivery service cost is the ratio of the sum of total cost $C_i$ on the sum of the quantity in different modes in each delivery station, the total delivery service cost function can be determined, i.e.,

$$C_c = \frac{1}{n} \sum_{i=1}^{n} \frac{C_i}{n_i}. \quad (16)$$

4. Delivery Service Capability

For the convenience of description, we provide the notations of the symbols involved in the analysis of last mile delivery service capability as shown in Table 2.

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Description</th>
<th>Symbols</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_B$</td>
<td>The basic delivery service capacity;</td>
<td>$A_T$</td>
<td>The time-limited delivery service capacity;</td>
</tr>
<tr>
<td>$v_i$</td>
<td>The maximum quantity of delivery pieces for the $i$th car;</td>
<td>$p_l$</td>
<td>The number of delivery workers;</td>
</tr>
<tr>
<td>$a_i$</td>
<td>The utilization rate of delivery service capacity for the $i$th car;</td>
<td>$l_i$</td>
<td>The average time for a piece delivery;</td>
</tr>
<tr>
<td>$b_i$</td>
<td>The average volume of a piece;</td>
<td>$t_r$</td>
<td>The average time for serving the customer;</td>
</tr>
<tr>
<td>$\beta_i$</td>
<td>The number of deliveries during the operation period for the $i$th car;</td>
<td>$t_s$</td>
<td>The time spent by the $i$th car in the delivery;</td>
</tr>
<tr>
<td>$A_R$</td>
<td>The reverse delivery service capability;</td>
<td>$r'_i$</td>
<td>The time spent by the $i$th car for serving the customer;</td>
</tr>
<tr>
<td>$h_r$</td>
<td>The number of working hours of a worker each day;</td>
<td>$A_I$</td>
<td>The storage capacity;</td>
</tr>
<tr>
<td>$m_r$</td>
<td>The number of working hours of reverse delivery;</td>
<td>$A_0$</td>
<td>The actual construction capacity of the delivery station;</td>
</tr>
<tr>
<td>$m_t$</td>
<td>The number of working hours of time-limited delivery;</td>
<td>$\lambda$</td>
<td>The utilization rate of storage capacity at the delivery station;</td>
</tr>
<tr>
<td>$n_r$</td>
<td>The number of operators who deals with the reverse delivery;</td>
<td>$\delta_0$</td>
<td>The number of storage turnover during the operation period.</td>
</tr>
</tbody>
</table>

In the logistics service for last mile delivery, the comprehensive delivery service capability can be affected by the service capabilities of each delivery link of an express enterprise. Generally, there are four main factors that can affect the delivery service capability, i.e., the basic delivery service capability $A_B$, the reverse delivery service capability $A_R$, the time-limited delivery service capability $A_T$, and the storage capability $A_I$. To facilitate the analysis, given the noncompetition of the regional last mile delivery market, we assumed that customers are completely satisfied with the delivery services provided by the express enterprises. According to the literature [35], the calculation equations of these four capacities can be determined, i.e.,

$$A_B = \alpha_i \beta_i \sum_{i=1}^{m} \frac{v_i}{b_0}, \quad (17)$$

$$A_R = \frac{m_r n_r}{l_0 p_l}, \quad (18)$$

$$A_T = \frac{m_t p_l}{(t_r + t_s) w}, \quad (19)$$

$$A_I = A_0 \delta_0 s, \quad (20)$$

where $t_r = \frac{t_r n_0}{t_0 v_0}$ and $t_s = \frac{t_s n_0}{v_0 v_0}$.
According to the barrel theory, the delivery service capability of an express enterprise will be determined by the weakest part of its various service capabilities, i.e., the delivery service capability \( A_M \) is the minimum value of \( A_B, A_R, A_T, \) and \( A_I \), and it can be formulated as follows,

\[
A_M = \min(A_B, A_R, A_T, A_I).
\] (21)

5. The Logistics Service Mode Selection for Last Mile Delivery

Based on the above analysis of delivery service cost and delivery service capability, according to the literature [36], DCA and DSCA of express enterprises can be determined.

Let \( X \) denote DCA, it can be described by the cost \( C_e \) of delivery service of each piece for the express enterprise and the average cost \( \overline{C_e} \) of delivery service of each piece in the delivery market. Specifically, \( X \) can be expressed as

\[
X = \frac{C_e}{\overline{C_e}}.
\] (22)

According to Equation (22), if the average cost \( \overline{C_e} \) in the delivery market is fixed, the smaller the delivery service cost \( C_e \) of the express enterprise is, the greater the delivery service cost advantage \( X \) of the express enterprise is.

Let \( Y \) denote DSCA, it can be described by the maximum number of delivered pieces per unit time of the express enterprise (i.e., delivery service capability \( A_M \)) and the number of pieces \( n_a \) needed to be delivered by the express enterprise per unit time. Specifically, \( Y \) can be expressed as

\[
Y = \frac{A_M}{n_a}.
\] (23)

According to Equation (23), if the number of pieces \( n_a \) needed to be delivered by the express enterprise per unit time is fixed, the larger the maximum number of delivered pieces \( A_M \) per unit time of the express enterprise is, and then the greater the advantage \( Y \) of delivery service capability is.

Based on above analysis, according to Figure 1 and the DCA and DSCA of logistics service for last mile delivery of the express enterprise, the logistics service mode for last mile delivery can be determined.

6. Case Analysis

In this section, to show the feasibility and effectiveness of the proposed method, we provide a case analysis of YD Express for the logistics service mode selection for last mile delivery. Specifically, for the secondary delivery center of SH Street in Shenyang City, there are seven last mile delivery service branches \( B_1, B_2, \cdots, B_7 \), as shown in Figure 2. The delivery quantities of these branches are different. Through interviews and conversations with the managers of each branch, we know that the delivery quantities of these branches are 100 pieces per day, 50 pieces per day, 400 pieces per day, 100 pieces per day, 200 pieces per day, 200 pieces per day, and 200 pieces per day, respectively.

Since the delivery service demand in this area continues to expand, in order to relieve the delivery service pressure of the seven branches, YD Express decide to establish a new delivery service branch \( B_{\text{new}} \) in this area as shown in Figure 2. By re-dividing the delivery service scope for branches \( B_1, B_2, \cdots, B_7 \), and \( B_{\text{new}} \) in this area, the number of pieces needed to be delivered by branch \( B_{\text{new}} \) will be about 150 pieces/day. In the following, for branch \( B_{\text{new}} \), we briefly give the calculation process of delivery service cost advantage and delivery service capability advantage. On the basis, we show the process of the logistics service mode selection for last mile delivery.
6.1. Calculation of Delivery Service Cost Advantage

The delivery service of branch $B_{\text{new}}$ is basically the same as one of other branches, but time-limited delivery service has not been provided for the time being. The daily working time is from 8:00 to 18:00, where the normal working time is 8 h and the abnormal working time is 2 h. The delivery vehicles are electric vehicles, and each electric vehicle can load and deliver 100–200 pieces with an average speed of 40 km/h and 10 h maximum continuous working time. The average time for serving a customer is 3 min. The average cost per unit time is 10 CNY/h. The average cost per unit distance is 0.16 CNY/km. The success probability of the first-time delivery is 95%.

According to the existing statistics, the probability of reverse delivery of pieces is 5%, the unit time processing cost of reverse logistics is 15 CNY/h, and the reverse logistics processing time of each piece is 0.25 h. The unit construction cost for building a delivery station is 10,000 CNY/m². According to the existing statistics, the probability of reverse delivery is 5%, the processing cost of reverse delivery per unit time is 15 CNY/h, and the processing time of each piece in reverse delivery is 0.25 h. The unit construction cost $C$ for a delivery service station is 10,000 CNY/m². According to the practical situation, the minimum construction capacity $V$ of the delivery service station will be 30 m³, and thus the corresponding construction cost $F = CV$ is 300,000 CNY.

Given that the average volume $U$ allocated for each piece is 0.3 m³/piece, then the minimum number of pieces for branch $B_{\text{new}}$ can be determined by $Q = V/U$, i.e., 100 pieces. Investment cost coefficient can be determined by $E_0 = UC$, i.e., 3000 CNY/piece. In addition, we considered that the economies of scale index $\alpha$ is 0.5, the depreciation period is 20 years, the annual management cost $C_M$ is 20,000 CNY/year, and the annual additional special processing cost $C_E$ is 10,000 CNY. On this basis, the last mile delivery service cost of branch $B_{\text{new}}$ can be determined according to Equations (1)–(6) and (11), and the specific calculation results are as follows.

$$C_B = C_B^1 + C_B^2 = 125.74 + 6.29 = 132.03,$$

$$C_R = C_R^1 + C_R^2 = 40.70,$$

$$C_F(Q_0) = 44,$$

$$C'_M = 20000 / 365 = 54.79,$$

$$C_E = 10000 / 365 = 27.40.$$
Furthermore, the total delivery service cost $C_{sum}$ of branch $B_{new}$ can be determined, i.e.,

$$C_{sum} = C_B + C_R + C_F + C_M + C_E = 298.92.$$  

Then, the delivery service cost of each piece can be determined, i.e., $C_e = C_{sum}/n_a = 298.92/150 = 1.99$.

In the current market situation, SF Express adopts the self-run mode and YD Express adopts outsourcing mode, while ST Express, YT Express, and ZT Express adopt alliance mode. In the following, the delivery service costs of each piece are analyzed for three logistics service mode by the examples of these enterprises in practice.

### 6.1.1. Self-Run Mode

There are three delivery service stations of SF Express in self-run mode in this area, i.e., $A_1$, $A_2$, and $A_3$, the specific operation situations are illustrated below.

1. The number of pieces for last mile delivery in branch $A_1$ is 80 pieces per day. According to Equation (13), we know $C_{a_1}^1 = 205.72$.
2. The number of pieces for last mile delivery in branch $A_2$ is 300 pieces per day. Then, we know $C_{a_2}^2 = 563.48$.
3. The number of pieces for last mile delivery in branch $A_3$ is 400 pieces per day. Then, we know $C_{a_3}^3 = 657.80$.

Furthermore, we know that $C_{a} = \sum_{i=1}^{3} C_{a_i}^i = 1427$ and $n_a = 80 + 300 + 400 = 780$.

### 6.1.2. Outsourcing Mode

The branches $B_1$, $B_2$, $B_3$, $B_4$, $B_5$, $B_6$, and $B_7$ of YD Express are in outsourcing mode, and the corresponding number of delivery pieces are 100 pieces per day, 50 pieces per day, 400 pieces per day, 100 pieces per day, 200 pieces per day, 200 pieces per day, and 200 pieces per day, respectively. The average cost $C_e$ of each piece is 2, i.e., $C_e = 2$.

Obviously, $C_b = C_e \sum_{i=1}^{7} n_i^b = 2500$ and $n_i^b = 100 + 50 + 400 + 100 + 200 + 200 + 200 = 1250$.

### 6.1.3. Alliance Mode

ST Express, YT Express, and ZT Express form the delivery service alliance, the alliance has five delivery service stations, i.e., $D_1$, $D_2$, $D_3$, $D_4$, and $D_5$, and the specific operation situations are illustrated below.

1. The three express enterprises in branch $D_1$ need to deliver 130 pieces per day, 100 pieces per day, and 80 pieces per day, respectively, and thus the total number is 310 pieces per day. Then, we know from Equation (13) that $C_{c_1}^1 = 603.66$.
2. The three express enterprises in branch $D_2$ need to deliver 280 pieces per day, 180 pieces per day, and 210 pieces per day, respectively, and thus the total number is 670 pieces per day. Then, we know from Equation (13) that $C_{c_2}^2 = 1147.631$.
3. The three express enterprises in branch $D_3$ need to deliver 300 pieces per day, 150 pieces per day, and 250 pieces per day, respectively, and thus the total number is 700 pieces per day. Then, we know from Equation (13) that $C_{c_3}^3 = 1050.19$.
4. The three express enterprises in branch $D_4$ need to deliver 150 pieces per day, 180 pieces per day, and 100 pieces per day, respectively, and thus the total number is 430 pieces per day. Then, we know from Equation (13) that $C_{c_4}^4 = 769.82$. 


5. The three express enterprises in branch $D_5$ need to deliver 75 pieces per day, 50 pieces per day, and 60 pieces per day, respectively, and thus the total number is 185 pieces per day. Then, we know from Equation (13) that $C_e^5 = 381.51$.

Furthermore, we know $C_e = \sum_{i=1}^{5} C_e^i = 3952.81$ and $n_i^f = 310 + 670 + 700 + 430 + 185 = 2295$. According to the above analysis, the average cost of each piece in alliance mode can be determined, i.e., $\bar{C}_e = (C_a + C_b + C_c) / (n_1^p + n_2^p + n_3^p) = 1.82$.

### 6.2. Calculation of Delivery Service Capability Advantage

The last mile delivery service capacity of branch $B_{new}$ in YD Express contains four aspects, i.e., $A_B$, $A_R$, $A_T$, and $A_I$. In branch $B_{new}$, there are two delivery vehicles, two operators for processing pieces, and two workers for practical delivery service. The values of other parameters are shown in Table 3.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$v_1$</th>
<th>$v_2$</th>
<th>$\alpha_1$</th>
<th>$\alpha_2$</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$m_r$</th>
<th>$m_i$</th>
<th>$\delta_0$</th>
<th>$A_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values</td>
<td>30 m$^3$</td>
<td>60 m$^3$</td>
<td>60%</td>
<td>70%</td>
<td>2</td>
<td>1</td>
<td>3.5 h</td>
<td>10 h</td>
<td>0.3</td>
<td>150</td>
</tr>
</tbody>
</table>

According to Equations (17)–(20), the delivery service capabilities of each aspect can be obtained, i.e., $A_B = 260$, $A_R = 280$, $A_T = 260$, and $A_I = 255$, respectively.

On the basis, according to Equation (21), the last mile delivery service capability of branch $B_{new}$ in YD Express can be determined, i.e., $A_M = \min(A_B, A_R, A_T, A_I) = \min(260, 280, 260, 255) = 255$.

### 6.3. The Selection of Logistics Service Mode for Last Mile Delivery

According to above calculation equation, we can determine the two-dimensional index values of the last mile delivery service cost advantage and delivery service capability advantage of branch $B_{new}$ in YD Express, i.e., $X = \bar{C}_e/C_e = 1.82/1.99 = 0.91$ and $Y = A_M/n_a = 255/150 = 1.7$. Thus, the corresponding two-dimensional coordinate value of branch $B_{new}$ in YD Express is $(0.91, 1.7)$, it is shown in Figure 3.

![Figure 3. Logistics service mode selection for last mile delivery for branch $B_{new}$ in YD Express.](image_url)

It can be seen from Figure 3 that the delivery service cost advantage $X$ of branch $B_{new}$ is 0.91, obviously, it is lower than the market average. The delivery service capability advantage $Y$ of branch $B_{new}$ is 1.7, and it is higher than the market average.
According to the framework of logistics service mode selection for last mile delivery based on a two-dimensional matrix decision model in Section 2, we know that the optimal logistics service mode for last mile delivery for branch $B_{\text{new}}$ in YD Express is alliance mode, and branch $B_{\text{new}}$ should be the leader in the alliance relationship.

7. Conclusions

In this paper, we proposed a mode selection method for last mile delivery considering delivery service cost advantage and delivery service capability advantage. We first analyzed the two dimensions, and further proposed a framework of logistics service mode selection for last mile delivery based on a two-dimensional matrix decision model. Then, we gave the calculation process of last mile delivery service cost and last mile delivery service capacity. Furthermore, we showed the optimal mode selection process for last mile delivery. On the basis, we obtained two managerial implications. First, last mile delivery service cost and capacity are usually different for different express enterprises and different logistics service modes, so the express enterprise needs to determine the last mile delivery service cost and capacity for each potential logistics service mode. Secondly, the express enterprise needs to simultaneously consider the delivery service cost advantage and the delivery service capacity advantage in the selection of logistics service mode for last mile delivery.

Compared with the existing methods on the logistics service mode selection, our method can better reflect the characteristics of last mile delivery service and has the advantages of clear concept and easy operation. The proposed method can enrich or perfect the research content on the logistics service mode selection and can provide strong support for the operation management practice of express enterprises. For the further research, we will focus on the logistics service mode selection for last mile delivery considering the consumer satisfaction in competitive delivery market, and study the logistics service mode selection for last mile delivery considering the multiagent participation based on game theory.

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References


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