Subsidy strategy of sharing logistics platform

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Abstract

Sharing logistics platform can effectively realize the sharing of idle logistics resources and maximize the utility of logistics resources utilization by publishing and matching the supply and demand information of logistics resource. For sharing logistics platform, subsidy strategy plays a significant role in winning market competition. Therefore, how to establish an effective subsidy scheme is a burning issue. By analyzing the problems in the transaction orders of drivers and consignor on the sharing logistics platform, this paper estimates the subsidy strategy on the following three aspects: (1) establish a dynamic model of freight supply and demand matching according to the freight cost and determine the impact of different subsidy policies on the platform usage; (2) evaluate the solution of different subsidy policies to the matching problem of vehicles and goods, and determine the optimal subsidy scheme based on the evaluation results; (3) establish the subsidy model based on platform maximum benefit and social welfare optimization and analyze a practical case of "Huochebang" (a Sharing logistics platform). The analysis results show that the model constructed in this paper can be well applied to the subsidy problem of sharing logistics platform and assist the platform to establish the most suitable subsidy policy to achieve the optimal economic benefits.

Keywords Sharing logistic platform · Subsidy strategy · Two-side market

Introduction

The new bilateral platform has developed overwhelmingly in recent years, which is represented by the Airbnb online travel housing rental platform established in 2008 and Uber Intelligent Network car-hailing Service Company established in 2009. It is increasingly popular that many companies start to pay attention to the sharing economy business. It is commonly observed that these bilateral platforms can relieve the information asymmetry between supply and

demand, and reduce the obstacle of matching supply and demand. Moreover, it relaxes the capacity constraints of the traditional bilateral market by sharing the idle resources.

Because of the characteristics of bilateral platforms of sharing economy, the pricing strategy of service products is different from the traditional bilateral markets. As a supplement to the pricing strategy, subsidies play an important role in the process of adjusting the supply and demand balance of bilateral users, especially in stage of training users in the market. For instance, China's Didi taxi company and Kuaidi taxi company have provided total subsidies of 2 billion yuan to users from January to March 2014. Such generous subsidies even enabled many passengers to travel free of charge. Therefore, the number of registered users soared and the market had already up to 49 million users by the second quarter of 2014. The American travel-sharing platform Lyft gives drivers a 5% bonus return on each order in the promotion stage.

Under the mode of sharing economy, the subsidy strategy is to make corresponding adjustments according to the characteristics of the platform. For example, in recent years, the ride-hailing service platforms Didi and Uber have adopted the different competitive strategies in the fierce competition.

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Didi mainly uses the way of subsidizing passengers to compete for the market, while Uber tends to subsidize drivers. In 2015, Uber spent \$1 billion dollars to subsidize passengers and drivers in China. At that time, when the drivers completed an order, they received a subsidy of three times the order. At the same time, customers can also get a lot of vouchers so that some customers can take a taxi for free. Obviously, Uber hoped to build its bilateral network in China, and the registered users soared to 250 million. From this competition, it is observed that different subsidy strategies have different impacts on the development of bilateral platforms for sharing economy. Therefore, subsidies play an essential role in the process of winning market competition.

Yet, given these multiple examples and benefits, the subsidy strategy of sharing logistics platform is still an issue. There are few literatures that study the subsidy strategy of sharing logistics platform. This paper attempts to fill this gap and address the following research questions: (1) How to establish the evaluation index model of subsidy scheme? (2) How to determine the optimal subsidy scheme based on the evaluation?

To answer the aforementioned questions, we consider a dynamic model of freight supply and demand matching and analyze the impact of different subsidy policies on the platform usage. We also study the different subsidy policies to match the problem of vehicles and goods and establish the subsidy model based on platform benefit and social welfare. This study shows that our model can solve the subsidy problem of sharing logistics platform and establish the best subsidy policy to achieve the optimal economic benefits.

The remainder of this paper is organized as follows: Section "Literature review" outlines related literature. Then, we present the basic model framework in Section "Model framework". Section "Establishing the evaluation index model of subsidy scheme" establishes the evaluation index model of subsidy scheme and presents the model analysis. In Section "Practical analysis: Huochebang", we consider the model for the case of "huochebang". Section "Conclusion" elaborates the conclusions of the study.

Literature review

At present, there are few literatures directly studying on the subsidy strategy of sharing logistics platform. Most of the related research focus on the influence of subsidies in logistics operation and management on supply chain integration. Heinrich [1] mainly studies the rebate strategy between manufacturers and retailers or consumers. He believes that this rebate strategy was actually a kind of subsidy, which is used to encourage retailers' purchase behavior. Greenwood and Wattal [2] analyzes the issue of subsidies in sharing bicycles and finds that in the target

rebate contract of the sharing platform, it is only when the target sales volume exceeds the target that the rebate can be obtained. Our study differs from the above literature in that we consider subsidy policies to the matching problem of vehicles and goods of sharing logistics platform.

Unlike the abovementioned channel rebate, Malhotra and Alstyne [3] mainly analyze the return of sharing economy platform to consumers, and focus on the negative impact of subsidy strategy of sharing economy platform. Fagerstr [4] analyze the factors of the success of the sharing economy and point out that subsidies to consumers are the most effective way to obtain customers. As a special bilateral market, the logistic under the sharing economy is essentially different from the traditional supply chain market. Kung and Zhong [5] state that for a platform, the most critical problem is to provide sufficient incentives for both sides to be large enough. Kaffle et al. [6] makes a study of an on-demand service platform that faced time-sensitive customers and self-scheduling providers.

Pazaitis et al. [7] analyze the subsidy mechanism of sharing logistics platform for different objects by using bilateral market pricing theory in the game between different subsidized objects. Punel [8] and others discuss how self-scheduling can affect the optimal price of the platform. Fraiberger and Sundararajan [9] take the monopoly market situation into account, construct the game model with the goal of profit maximization and social welfare maximization of sharing logistics platform. They obtain the optimal subsidy object and subsidy level under different environments. Wang et al. [10] state that the ride-sharing systems may be designed to match riders and drivers to maximize system performance improvement. However, each individual participant may not obtain maximum benefit from system-optimal matches. Benjaafar et al. [11] states that they study social-welfare maximizing platforms and compare equilibrium outcomes under both in terms of ownership, usage, and social welfare. Wang et al. [12] explains that in the ridesharing program, encouraging rider or drivers to participate by subsidizing is indispensable and it is difficult to carry out. Zhou et al. [13] does some research on how an on-demand platform matches providers to customers. Fang et al. [14] states that in the early stages, the tradeoff is often difficult for sharing platforms to satisfy, in order to avoid supply shortages by giving subsidies in the sharing platforms.

Cohen and Kietzmann [15] extend the monopoly market of sharing economy platform to the market situation of duopoly competition. Based on Hotelling model, they establish game models under the structures of the single ownership, partial multi-ownership and complete multi-ownership of users, then obtain the market structure of optimal subsidy object and the optimal equilibrium market in different environment. In contrast to these literatures, this paper considers a dynamic model of freight supply and demand matching

and analyze the impact of different subsidy policies on the platform usage. We also establish the subsidy model based on platform benefit and social welfare.

According to the current situation, the research on supply chain coordination and its subsidy strategy is very mature, and the international research has been carried out from different subsidy objects, different subsidy levels and different subsidy sequences. When providing subsidies to shippers and drivers, the profit of the platform will also be guaranteed. Therefore, the higher social welfare profit means that the higher satisfaction between shippers and drivers. It could maximize the social welfare by subsidizing drivers and shippers in the platform. In order to ground the theoretical work in this paper, we provide an empirical exploration of a sharing platform. In order to fit and validate our model, we use data from “Huochebang” which is the largest logistics information sharing platform in China. The research in this field provides a scientific basis and basic tools for this paper to carry out the study on subsidy strategy of sharing logistics platform. After the subsidy, the number of drivers will increase and the waiting time of shippers will reduce. It is meaningful for the development of the platform if provided subsidy. As the load rate of truck is improved, the driving distance of the driver can decrease, which can greatly reduce the consumption of fuel resources and relieve gas emissions, so it will play a very positive role in protecting the air environment. On the one hand, the subsidy can encourage more shippers and drivers to participate in this platform; On the other hand, it promotes the balance between supply and demand of the Huochebang platform.

Model framework

In the model setup, the subsidy standards of different levels are formulated based on the use of “Huochebang” information platform without subsidy and the problems in the transaction order between the platform driver and the consignor. We consider the minimum distance from the driver’s initial location to the customer’s location and the demand of the freight destination and establish the evaluation index of the total empty mileage according to the actual physical meaning. Next, we get the dynamic matching model of freight supply and demand by considering the freight cost and set up the different levels of freight subsidy based on the freight distribution scheme. Therefore, the models of the influence of different subsidy policies on the use of the platform are established. Finally, we construct the evaluation of the matching of vehicles and goods by different subsidy policies, and the optimal subsidy scheme is determined by the evaluation results. The implementation of subsidy scheme has two main functions. On the one hand, it can increase more cargo owners and drivers who use the “Huochebang” platform. On the other hand, it can promote the “Huochebang” platform’s balance between supply and demand. To establish a reasonable subsidy scheme, we consider both truck driver and cargo owner aspects. Table 1 shows the meaning of symbols in the subsidy model.

Dynamic model for optimizing freight supply and demand matching

The dynamic model of supply and demand matching can determine the one-to-one matching between each freight car and the consignor through the platform. It is assumed that at time t the number of truck driver users who can accept shipment orders on the “Huochebang” platform is D , while

Table 1 Symbol definition

Symbol	Meaning
J	The set of points where the goods should arrive at the destination J
I	The point set of the owner’s location or the original location of the goods I
$G_{ij}(t)$	The cost function of transporting goods by the truck of the i driver user in the j consignor user
C	The minimum cost of transporting goods to the j destination by the i truck at t time
α_{ij}	The i driver user corresponds to the freight demand of the j consignor user
$m_1(t)$	The amount of subsidy paid by the platform to the consignor (yuan)
$m_2(t)$	Amount of subsidy paid by the platform to lorry drivers (yuan)
d_{ij}	Freight mileage from location i to location j (km)
p'	Fuel charge per kilometer for current freight orders (yuan/km)
λ	Proportion coefficient of service charge for each freight information published by the consignor user
p_j	The freight rate of an order traded by the owner j (yuan)
x'_j	Total number of shipping information published by owner user j
x''_j	Number of freight orders traded by consignor user j

the number of freight owner users who publish the source information is Q . When $Q > D$, demand exceeds supply and other non-cash subsidies to driver users will be increased at this time to increase the number of single driver users on the platform. When $Q \leq D$, the supply is in excess of demand and the Q driver is actually assigned to the cargo owner who needs the freight.

We take the total cost C as the objective function. Note that the freight demand α_{ij} measures that the i driver user (the initial freight location of the i driver user is i) corresponds to the freight demand of the j cargo owner user (the j cargo owner's freight destination is also j). $\alpha_{ij} \in \{1, 0\}$. $G_{ij}(t)$ is the cost of the consignor user using the i driver user's lorry to transport the goods at t time. If the lorry driver already has an order arrangement at t time, $G_{ij}(t) = \infty$, which indicates that the current distribution of goods cannot be accepted. The goods will be transported by a goods vehicle at t time. The optimized supply and demand matching model based on the minimum cost to the j destination can be written as follows:

$$\min C = \sum_{j=1}^Q \sum_{i=1}^Q G_{ij}(t) \alpha_{ij} \quad (1)$$

$$s.t. \begin{cases} \sum_{i=1}^D \alpha_{ij} = 1 & j = 1, \wedge, Q \\ \sum_{j=1}^D \alpha_{ij} = 1 & i = 1, \wedge, Q \\ \alpha_{ij} = 0 & \text{or } 1 \end{cases}$$

In formula (1), we can suppose that there are five truck drivers who can take orders, namely A, B, C, D and E, and there are four users who release the source information of goods, named G, K, L and M. in order to guarantee drivers match the users, we provide virtual user N. by calculate, the A-L, B-K, C-L, D-M, E-N. E-N illusive that the drive E no need to take orders.

Establishment of a balanced distribution subsidy model

1. Subsidies to driver users

According to the above dynamic distribution model of supply and demand matching, we establish a subsidy model of balanced distribution based on the transportation cost of freight orders assigned by drivers and users.

The reasons why driver users are unwilling to accept some freight orders mainly have two aspects: the freight rate is low and the cost of freight is high, which makes the profit of transportation relatively low; On the other hand, the freight demand of freight destination is small. When the driver delivers the

goods to the destination, the probability of receiving another freight order at the destination is small. It means that the freight is most likely to return empty, which leads to the higher freight costs.

As shown by these two reasons above, the driver users who receive these two types of orders are given the corresponding multiple subsidy amount. m_0 is the amount of subsidy if and only if the transport mileage is less than L_0 . The fuel cost in the current transportation process is p' (yuan/km). We can write the resulting subsidy function of driver users as

$$m_2(t) = [d_{ij} - L_0] \cdot \frac{m_0}{L_0} + m_0 + P_{ij}(t) \cdot p' d_{ij}$$

$$= [d_{ij} - L_0] \cdot \frac{m_0}{L_0} + m_0 + \frac{\exp[\theta(-d_{ji} + \mu Q_j)]}{\sum_{i \in I} \exp[\theta(-d_{ij} + \mu Q_j)]} p' d_{ij}. \quad (2)$$

where d_{ij} indicates the distance from place of departure i to destination j , and $P_{ij}(t)$ is the probability of empty load of destination j when the driver users accept the order at t time.

2. Subsidies to consignor users

The cargo owners of the "Huochebang" platform mainly consider reducing the behavior of the freight owners to release freight information on the screen and decreasing the impact of the early charging measures to users. Therefore, we formulate two kinds of subsidy measures. Firstly, attract the new cargo owner users and give the new user a special red envelope subsidy. Do not charge the service fee for the first x_0 shipping information issued by the new user. Secondly, subsidize the freight order according to the proportion of the information.

We define that x'_j is the total number of information released by the owner before the order. x''_j is the number of previous freight orders. Note that the service charge for publishing each freight information is λ times of the freight rate of the second freight information. Thus, the subsidy model of the consignor user is given by

$$m_1(t) = \frac{x'_j}{x''_j} \cdot \lambda \cdot p_j, \quad (3)$$

where p_j denotes the total freight rate of the freight order for the consignor j .

Establishing the evaluation index model of subsidy scheme

"difficult to hail" index model

In practice, due to the influence of freight rate, the distance to the destination where the goods are sent and the freight demand density, many truck drivers choose not to take orders when they see the freight information released by

the cargo owners on the platform. During the rush hour of freight demand, the supply of goods vehicles cannot meet the transportation demand of the platform, which leads to the phenomenon that many consignors have to wait a long time to send out the goods. Even when the delivery deadline doesn't reach, the freight driver is not contacted. Referring to the similar situation of Didi taxi in our daily life, the problem of truck supply faced by the "Huochebang" cargo owners is called the "difficult to hail" problem. Table 2 shows the meaning of symbols in the "difficult to hail" index model.

In the field of freight transportation, the problem of "ride hailing difficulty" is mainly decided by the length of time T of the consignor waiting to pick up the order and the empty load rate δ of the truck. The situation that the driver refuses to accept the order will eventually lead to the extension of the waiting time of the owner, so it can be attributed to the waiting time t of the owner. Note that R is the "difficult to take a taxi" indicator, which can be written as

$$R = c_1 T + \frac{c_2}{\delta}. \quad (4)$$

We denote c_1 and c_2 as the constant-coefficients. R is increasing in T , and R is decreasing in δ . Therefore, the smaller the waiting time of the consignor and the higher the empty load rate of the freight car, the smaller the degree of "ride hailing difficulty". Similarly, the shorter the time it takes for the owner to reach an agreement with the truck driver, the earlier the cargo owner can deliver the goods.

1. Establishment of time length model for consignors

When $Q \geq D$, the number of trucks receiving orders on the platform cannot meet the demand of the freight supply. The waiting time of cargo owner users depends on the number of users who need to be transported on the platform in the same period of time, so the waiting time can be measured according to the difference between demand Q and supply D . When $Q < D$, there are more truck drivers who can receive orders than cargo owners waiting for orders on the platform. It is measured by the larger value of the inverse function of the minimum satisfactory time of

the consignor waiting for order and the difference between supply and demand. Thus, the model of equal order length T of the consignor is

$$T = \begin{cases} b_1(Q - D) & Q \geq D \\ \max \left\{ T_0, \frac{b_2}{D - Q} \right\} & Q < D \end{cases}. \quad (5)$$

Let T_0 denote the minimum satisfactory time (i.e., the longest waiting time that the owner can accept when the supply exceeds the demand). b_1 and b_2 are constant proportional coefficients of the conversion time.

2. Establishment of No-load Rate Model of Freight car

When $Q \leq D$, the no-load rate of freight car is measured by the difference between supply D and demand Q . When $Q > D$, it is measured by the larger value of the inverse function of the maximum satisfaction degree of the freight car empty load rate and the difference between demand and supply. Therefore, the model of no-load rate is given by

$$\delta = \begin{cases} \max \left\{ \delta_0, \frac{b_3}{Q - D} \right\} & Q > D \\ b_4(D - Q) & Q \leq D \end{cases} \quad (6)$$

We denote δ_0 as the maximum satisfaction of no-load rate (the value of). b_3 and b_4 are the constant proportional coefficients which are transformed into no-load rate when the supply exceeds demand and the no-load rate is the smallest.

3. Establishment of the model of supply and demand function

Based on the demand function $Q_0(t)$ and supply function $D_0(t)$ in the supply–demand matching problem, the two-way subsidy scheme is added. We get the new demand function $Q(t)$ and supply function $D(t)$ as follows:

$$Q(t) = [k_1 m_1(t) - k_2 m_2(t) + k_3 m_3(t)] + Q_0(t) \quad (7)$$

Table 2 Variable definition

Symbol	Meaning
μ	The conversion coefficient of transforming the influence of freight demand on utility value into the influence of freight distance on utility value
T	How long does the consignor wait to receive the order after the platform publishes the source information
R	"ride hailing difficulty" index
δ	Truck load rate
$Q(t)Q(t)$	Freight demand function
$D(t)$	Freight supply function
$m_3(t)$	Other non-cash subsidies
W	The difference between freight demand and supply

$$D(t) = [l_1 m_1(t) + l_2 m_2(t) + l_3 m_3(t)] + D_0(t). \quad (8)$$

where k_1 , k_2 and k_3 are the proportional coefficients of the influence of subsidy mode on freight demand. l_1 , l_2 and l_3 are the proportional coefficients of the influence of subsidy mode on freight car supply. When the subsidy amount to the driver user is increased, the driver will be promoted to receive the order and the waiting time of the owner who publishes the goods source will become shorter. In this case, the demand for the freight car will decrease in the same period of time, so $m_2(t)$ has a negative impact on the freight demand function $Q(t)$.

Therefore, the difference between demand and supply can be written as.

$$\begin{aligned} W &= |Q(t) - D(t)| \\ &= |(k_1 - l_1)m_1(t) + (-k_2 - l_2)m_2(t) + (k_3 - l_3)m_3(t) + Q_0(t) - D_0(t)| \\ &= |n_1 m_1(t) + n_2 m_2(t) + n_3 m_3(t) + Q_0(t) - D_0(t)| \end{aligned} \quad (9)$$

We assume that $n_1 = k_1 - l_1$, $n_2 = -k_2 - l_2$, $n_3 = k_3 - l_3$, and the subsidy ratio coefficient n_2 for truck drivers must be negative. After the implementation of the subsidy scheme, the ideal result is to achieve a balance between supply and demand, i.e., $W = 0$. Therefore,

$$\begin{aligned} W &= Q(t) - D(t) \\ &= (k_1 - l_1)m_1(t) + (-k_2 - l_2)m_2(t) + (k_3 - l_3)m_3(t) + Q_0(t) - D_0(t) = 0. \end{aligned} \quad (10)$$

As the coefficient $' - k_2 - l_2'$ of the $m_2(t)$ must be negative, $(-k_2 - l_2)m_2(t)$ is moved to the right of the above equation. We know that

$$\begin{aligned} (k_2 + l_2)m_2(t) &= (k_1 - l_1)m_1(t) + (k_3 - l_3)m_3(t) + Q_0(t) - D_0(t) \Rightarrow \\ m_2(t) &= \frac{k_1 - l_1}{k_2 + l_2}m_1(t) + \frac{k_3 - l_3}{k_2 + l_2}m_3(t) + \frac{Q_0(t) - D_0(t)}{k_2 + l_2}. \end{aligned} \quad (11)$$

By (11), we can obtain the function relation of $m_2(t)$, $m_1(t)$, and $m_3(t)$. Calculate the partial derivatives of $m_2(t)$ and $m_3(t)$, respectively, and assume the partial derivatives are zero. We get

$$\frac{\partial m_2(t)}{\partial m_1(t)} = \frac{k_1 - l_1}{k_2 + l_2} = 0 \Rightarrow k_1 = l_1 \quad (12)$$

$$\frac{\partial m_2(t)}{\partial m_3(t)} = \frac{k_3 - l_3}{k_2 + l_2} = 0 \Rightarrow k_3 = l_3. \quad (13)$$

The above formulas indicate that if the subsidy scheme allows the difference between demand and supply to reach an ideal state of 0, the condition at this extreme value is $k_1 = l_1$ and $k_3 = l_3$. Therefore,

$$m_2(t)^* = \frac{Q_0(t) - D_0(t)}{k_2 + l_2}. \quad (14)$$

This subsidy scheme can make supply and demand reach the ideal value of $m_2(t)$ in equilibrium state, when $k_1 = l_1$ and $k_3 = l_3$. There is no requirement for the value of $m_1(t)$ and $m_3(t)$, as long as the original subsidy condition is greater than zero. Therefore, the index of "ride hailing difficulty" is as follows:

$$R = \begin{cases} c_1 b_1 W + c_2 \max \left\{ \delta_0, \frac{b_3}{W} \right\} & Q > D \\ c_1 \max \left\{ T_0, \frac{b_2}{W} \right\} + \frac{c_2}{b_4 W} & Q \leq D. \end{cases} \quad (15)$$

Establishment of an evaluation model for the impact indicators of total social welfare

As the freight information sharing service platform that is similar to the "Huochebang" has already occupied a certain

market share in the freight market. Moreover, no relevant subsidy policy has been implemented before. Therefore, the "Huochebang", as the representative of the freight transport information service platform, have an impact on the current social welfare. In economics, the total social welfare is defined as consumer surplus and producer surplus. In freight industry, it is manifested as the residual value of freight owners and drivers. Maintaining consumer surplus is beneficial to improve user satisfaction and keep consumption stimulus, while While maintaining producer surplus is conducive to the sustainable development of freight transport industry. Thus, the functional relationship between the subsidy scheme and the total social welfare can be established, and the influence of the subsidy scheme on the social welfare can be quantitatively analyzed. Therefore, we can evaluate the feasibility of the scheme on the basis of the function relationship between the subsidy scheme and the total social welfare. Table 3 shows the meaning of symbols in the model.

There are two key factors affecting the evaluation of the "Huochebang" platform used by the consignor: the length of waiting time and the freight rate. The consignor's waiting time is related to the empty load rate of the freight car directly. The higher the empty load rate of the freight

car, the shorter the waiting time of the consignor. According to the Cobb–Douglas function of economics, we can quantify the freight demand that is influenced by freight rate and mileage.

$$L = k_1 p^\alpha t^\beta \quad (16)$$

$$t = k_2 V^\gamma, \quad (17)$$

where k_1 and k_2 are the elasticity coefficients of the demand decided by the traffic condition and spatial layout of the initial and destination. As the demand of freight cars is negatively correlated with freight prices and empty mileage, we can get $\alpha \leq 0$, $\beta \leq 0$, and $\gamma \leq 0$.

In the real life, when the delivery trucks arrive at destination j , they are transformed into empty freight vehicles after unloading. Therefore, the total empty trucks E_j near location j can be written as

$$E_j = D_j = \sum_{i \in I} q_{ij}. \quad (18)$$

The number of empty vehicles in the vicinity of the location j is the same as the number of trucks in the vicinity of the location j , which is acceptable to the "freight car" platform source order. It also is equal to the truck supply quantity D_j in the vicinity of the location j and the total amount of the truck demand from the location i to the location j .

The probability of no load from location j to i is given by

$$P_{ji} = \begin{cases} \frac{\exp[\theta(-d_{ji} + \mu Q_j)]}{\sum_{i \in I} \exp[\theta(-d_{ij} + \mu Q_j)]} & i \neq j \\ 0 & i = j. \end{cases} \quad (19)$$

The above formula shows that the larger the personal characteristic correction value θ of the truck driver, the smaller the uncertainty of the characteristic value of the road network and the freight demand, and the more accurate the cargo matching situation.

In the process of waiting for the platform freighter to release the cargo source, the freight car driver should fully consider the parking place and the distribution characteristics of freight demand. The expected maximum freight satisfaction can be obtained with the shortest driving distance and freight cost. For the empty wagon located at J , the expected one-way no-load mileage of the vehicle searching to the next location I is

$$d_j = \sum_{i \in I} d_{ji} P_{ji}, \quad (20)$$

where d_{ji} is the shortest network path from location j to location i . According to the above formula (18), (19) and (20), the total empty mileage of the goods vehicle generated by the study can be written as

$$V = \sum_{j \in J} E_j d_j = \sum_{j \in J} \left(\sum_{i \in I} q_{ij} \cdot \sum_{i \in I} d_{ji} P_{ji} \right). \quad (21)$$

For a closed social model R , the residual value of a lorry I and the owner of its current service can be summarized as follows:

Table 3 Variable definition

Symbol	Meaning
L	Truck mileage (km)
p	Freight price per mile (yuan/km)
t	Owner's waiting duration (min)
V	No-load mileage of freight car (km)
α	Price demand elasticity
β	Waiting time requirement elasticity
γ	Empty mileage requires flexibility
q_{ij}	Total freight demand from the initial location I to the destination j of the goods
E_j	Total number of empty vans near initial location j
P_{ij}	Probability of departure from location I to location j unloaded goods vehicles
S_d	Residual value of goods vehicle (driver)
S_p	Owner's residual value
C	Average unit mileage cost
θ	The characteristic value of the driver's individual (including the degree of trust and preference of the platform)
μ	The conversion coefficient of transforming the influence of freight demand on utility value into the influence of freight distance on utility value

1. Residual value S_d of trucky:

$$S_d = pL - c(L + V). \quad (22)$$

By the above formulas (16) and (17), we can get

$$p = \left(\frac{L}{k_1 k_2^\beta V^{\beta\gamma}} \right)^{\frac{1}{\alpha}}. \quad (23)$$

2. For the current transportation service process, it is sensitive to the price change according to the research on the demand of the freight industry. Therefore, when the freight rate changes, the change rate of the freight demand will be greater than the change rate of the freight rate. In other words, the price elasticity coefficient $\alpha \leq -1$ is in line with the actual situation. Therefore, the residual value of the freight owner S_p is given by

$$S_p = \begin{cases} \int_0^{L_i} \left(\frac{x}{k_1 k_2^\beta V^{\beta\gamma}} \right)^{\frac{1}{\alpha}} dx - pL_i = \left(\frac{1}{k_1 k_2^\beta V^{\beta\gamma}} \right)^{\frac{1}{\alpha}} \cdot \frac{L_i \cdot \sqrt[\alpha]{L_i}}{\frac{1}{\alpha} + 1} - pL_i & \alpha < -1 \\ \infty & \alpha = -1 \end{cases} \quad (24)$$

The above formula indicates that when $\alpha < -1$, the total residual value for each freight process is

$$\begin{aligned} S_i &= S_d + S_p \\ &= pL_i - c(L_i + V) + \left(\frac{1}{k_1 k_2^\beta V^{\beta\gamma}} \right)^{\frac{1}{\alpha}} \cdot \frac{L_i \cdot \sqrt[\alpha]{L_i}}{\frac{1}{\alpha} + 1} - pL_i \\ &= \left(\frac{1}{k_1 k_2^\beta V^{\beta\gamma}} \right)^{\frac{1}{\alpha}} \cdot \frac{L_i \cdot \sqrt[\alpha]{L_i}}{\frac{1}{\alpha} + 1} - c_i(L_i + V). \end{aligned} \quad (25)$$

Based on the above relationship, the total social welfare S of closed society R can be obtained as follows:

$$S = \sum_{i \in R} S_i = \sum_{i \in R} \left[\left(\frac{1}{k_1 k_2^\beta V^{\beta\gamma}} \right)^{\frac{1}{\alpha}} \cdot \frac{L_i \cdot \sqrt[\alpha]{L_i}}{\frac{1}{\alpha} + 1} - c_i(L_i + V_i) \right], \quad \alpha < -1 \quad (26)$$

Combining with forms (16) and (17), we can get

$$L_i = k_1 p^\alpha k_2^\beta V^{\beta\gamma}. \quad (27)$$

Substituting (27) into (26), we know

$$\begin{cases} S = \sum_{i \in R} \left[\frac{p^{\alpha+1} \cdot \alpha}{\alpha+1} \left(k_1 k_2^\beta \right)^{\frac{1}{\alpha}} \cdot V_i^{\frac{\beta\gamma}{\alpha}} - c \left(k_1 k_2^\beta p^\alpha V_i^{\beta\gamma} + V_i \right) \right] \\ V = \sum_{i \in R} V_i = \sum_{i \in I} E_i d_i = \sum_{i \in I} \left(\sum_{j \in J} q_{ij} \cdot \sum_{j \in J} d_{ij} P_{ij} \right) = g(m', n') = g\left(m \frac{x_1}{r_1}, n \frac{x_2}{r_2}\right) \\ \alpha < -1 \end{cases} \quad (28)$$

$$S = \sum_{i \in R} \left[\frac{p^{\alpha+1} \cdot \alpha}{\alpha+1} \left(k_1 k_2^\beta \right)^{\frac{1}{\alpha}} \cdot V_i^{\frac{\beta\gamma}{\alpha}} - c \left(k_1 k_2^\beta p^\alpha V_i^{\beta\gamma} + V_i \right) \right] \quad (28)$$

As shown in formula (21), V is a binary function about (m, n) . Therefore, the following formula can be obtained:

$$\begin{cases} S = \sum_{i \in R} \left[\frac{p^{\alpha+1} \cdot \alpha}{\alpha+1} \left(k_1 k_2^\beta \right)^{\frac{1}{\alpha}} \cdot V_i^{\frac{\beta\gamma}{\alpha}} - c \left(k_1 k_2^\beta p^\alpha V_i^{\beta\gamma} + V_i \right) \right] \\ V = \sum_{k \in I} E_k d_k = g(m, n) \\ \alpha < -1 \end{cases}, \quad (29)$$

where M is defined as the degree of trust and preference of drivers in the "Huochebang" platform with subsidy. n is the amount of subsidy that increases the number of consignors. Therefore, the range of m and n is obtained as follows: $\theta \leq m \leq M\mu \leq n \leq N$, where θ indicates the degree of trust and preference of freight car drivers to the "freight car gang" platform without subsidy. μ represents the conversion coefficient which converts the influence of freight demand on the utility value into the conversion coefficient of the influence of freight demand on the utility value. M is the upper bound determined by the natural uncontrollable factor. And N is the upper bound that is decided by the cost of the platform company's investment in software and user use, the freight market, and the user consumption preferences.

We define that r_1 is the expected amount of subsidy (yuan/order) for freight car drivers in the freight market, and r_2 is the expectation (yuan/order) for the freight market to the owner user. In the actual subsidy decision, assume that the subsidy to the driver user is x_1 (yuan/single) and the subsidy to the consignor user is x_2 (yuan/single). Therefore, a new parameter pair (m', n') is established to show the stimulus effect of the subsidy x_1 and x_2 on the freight market.

$$m' = (x_1/r_1) * m \quad (30)$$

$$n' = (x_2/r_2) * n \quad (31)$$

By taking (30) and (31) into (29) (i.e., replace (mn) with $(m'n')$), we can get

Practical analysis: Huochebang

In this paper, the "Huochebang delivery" is mainly short distance freight transportation. Considering different cities have different economic levels and daily average freight demand, we select Shanghai, the first-tier city with rapid economic development in China, as the representative research object in order to study the best subsidy strategy. Due to the low freight demand in underdeveloped cities and "Huochebang" does not promote the short-distance freight transport business in these cities, we do not choose any representative cities in these underdeveloped cities.

Distribution of demand in Shanghai

Because the route city road on the actual map is complex, it is not convenient for practical research. This paper divides the Shanghai city into the grid to promote the research. We first choose Huangpu District (longitude 121.4818 east, latitude 31.2326 north) as the research center to establish a rectangular coordinate system.

Secondly, Qingpu District Passenger Transport Center (121.0879 E, 31.1581 N) and Nanhuizui Guanhai Park (121.9752 E, 30.8789 N) are selected as the main diagonal lines; Yongning Tangqiao (121.3092 E), the farthest end point in Baoshan District, and Weiba Road (121.2864 E, 30.7049 N), the farthest end point in Jinshan District are selected as auxiliary diagonal lines. After the above operation, the study grid area of Shanghai is formed.

Therefore, in the two-dimensional Cartesian coordinate system, the endpoint of Qingpu District, Pudong New area, Baoshan District and Jinshan District are $(-0.3937,$

$0.0745)$, $(0.4934, 0.3537)$, $(-0.1726, 0.2653)$, $(-0.1954, 0.527)$, respectively. The coordinate plane grid area is shown in the following Fig. 1:

According to the grid division, we collect the temporal and spatial distribution data of freight demand in the grid area to analyze the temporal and spatial distribution characteristics of the demand. According to the order location information of the "Huochebang" platform, a three-dimensional equivalent surface map of demand distribution is drew as follows:

In Fig. 2 above, the orange part indicates that the freight demand is large, while the blue part is relatively low. It can be seen that the short-distance freight demand in Shanghai is mainly distributed in Qingpu District, Jinshan District, the far urban area of Pudong New area, Baoshan District, especially Baoshan District and Jinshan District. Baoshan District is located at the intersection of Huangpu River and Yangtze River. Jinshan District's terrain is flat, agricultural output value is high, and more industrial parks are gathered in its convenient place, so lots of goods are transported to the center of the city every day. All the above situation leads to the freight demand for short-distance transportation in these two areas is relatively high. Huangpu District, the city center, is relatively small in short-distance freight demand, because most of the goods from the outskirts of the city are transported to the main urban area, such as Huangpu District, Xuhui District and Putuo District (because of its proximity to Putuo District, Jingan District, Changning District and Xuhui District) (121.449 E, 31.2175 N), the central area of Pudong New area (with Hongkou District and Yangpu District into one point) (121.5668 E, 31.2102 N) Yangpu District into one point), Baoshan District, Yuancheng District, Jiading District (121.2948 E, 31.4516 N), Minhang District (121.3068 E, 31.4516 N), Songhui District (East)

Fig. 1 Grid area division map in Shanghai

Fig. 2 Distribution map of freight demand in Shanghai

Through 121.2293, 30.9761 N), Qingpu District, Fengxian District (121.5164 E, 30.8365 N), eight grid points in Yuancheng District and Jinshan District, Pudong New area. Mark these 10 points in Fig. 3, as shown in the following figure:

According to the users' actual demand, this paper creates two grid points: the center of Huangpu District (121.449 E, 31.2175 N) (with Putuo District, Jingan District, Changning District and Xuhui District into one point, because they are close) and the center of Pudong New Area (121.5668 E, 31.2102 N) (with Hongkou District and Yangpu District into one point). About these suburb district, this paper creates eight grid points: Baoshan District-Jiading District (121.2948 E, 31.4516 N), Minhang District (121.3068 E, 31.4516 N), Songhui District (121.2293E, 30.9761 N) Through 121.2293, 30.9761 N), Qingpu District, Fengxian District (121.5164 E, 30.8365 N). Mark these 10 points in Fig. 3, as shown in the following figure:

In the Fig. 3 above, the actual distance between each two points can be calculated. According to the data, on the way to longitude and weft network, the length of dimension 1° in each region of the Earth is equal, and it can be converted to $1^\circ = 111$ km with the distance unit "km", while the distance and difference of longitude 1° are not equal. Therefore, this paper selects the latitude difference to calculate the actual distance between each location. First, the latitude difference between different locations is calculated by MATLAB software and then the latitude difference matrix is obtained as follows:

Combined with the latitude difference data in Table 4, the actual distance matrix between the points is calculated by MATLAB software, as shown in the following Table.

From Table 5, d_{ij} in the subsidy model can be determined. However, because it is a grid graph, in order to simplify the calculation of the model data, only the straight-line distance between the two grid points is taken into consideration, and

Fig. 3 Distribution map of Shanghai

the actual conditions such as route, urban road direction and so on are ignored. Therefore, the distance from location I to location j is equal to the distance from place j to location I in the grid graph route, so the shortest distance matrix between the points in this paper is symmetric. Besides, because the location of the central area is more concentrated, the distance is closer, and the freight demand between them is small, Jing'an District, Yongning district, and Xuhui District are merged into Huangpu District, while Hongkou District and Yangpu District are merged into the central area of Pudong New Area. Therefore, the above distance matrix values are only for rough study of this problem.

According to the historical orders' starting and destination on "Huochebang" platform during the period from

October 1, 2017 to October 1, 2018, the average daily demand between the connecting points is obtained. The freight demand between every two points in the grid is studied, and the following point-to-point demand Table 6 is made by MATLAB software.

In this paper, the demand of freight trucks owners indicates the number of trucks leaving the area, by tackling freight trucks in this area, we can draw a conclusion that mutual freight car demand between each location is an asymmetric demand matrix.

Table 4 Latitude difference between grid points in Shanghai

0	0.2653	0.0745	0.5277	0.3537	0.0224	0.1432	0.2003	0.3961	0.2565
0.2653	0	0.3398	0.793	0.619	0.2877	0.1221	0.4656	0.6614	0.5218
0.0745	0.3398	0	0.4532	0.2792	0.0521	0.2177	0.1258	0.3216	0.182
0.5277	0.793	0.4532	0	0.174	0.5053	0.6709	0.3274	0.1316	0.2712
0.3537	0.619	0.2792	0.174	0	0.3313	0.4969	0.1534	0.0424	0.0972
0.0224	0.2877	0.0521	0.5053	0.3313	0	0.1656	0.1779	0.3737	0.2341
0.1432	0.1221	0.2177	0.6709	0.4969	0.1656	0	0.3435	0.5393	0.3997
0.2003	0.4656	0.1258	0.3274	0.1534	0.1779	0.3435	0	0.1958	0.0562
0.3961	0.6614	0.3216	0.1316	0.0424	0.3737	0.5393	0.1958	0	0.1396
0.2565	0.5218	0.182	0.2712	0.0972	0.2341	0.3997	0.0562	0.1396	0

Table 5 Actual distance between locations in Shanghai grid map [(unit: km)]

0	29.4483	8.2695	58.5747	39.2607	2.4864	15.8952	22.2333	43.9671	28.4715
29.4483	0	37.7178	88.023	68.709	31.9347	13.5531	51.6816	73.4154	57.9198
8.2695	37.7178	0	50.3052	30.9912	5.7831	24.1647	13.9638	35.6976	20.202
58.5747	88.023	50.3052	0	19.314	56.0883	74.4699	36.3414	14.6076	30.1032
39.2607	68.709	30.9912	19.314	0	36.7743	55.1559	17.0274	4.7064	10.7892
2.4864	31.9347	5.7831	56.0883	36.7743	0	18.3816	19.7469	41.4807	25.9851
15.8952	13.5531	24.1647	74.4699	55.1559	18.3816	0	38.1285	59.8623	44.3667
22.2333	51.6816	13.9638	36.3414	17.0274	19.7469	38.1285	0	21.7338	6.2382
43.9671	73.4154	35.6976	14.6076	4.7064	41.4807	59.8623	21.7338	0	15.4956
28.4715	57.9198	20.202	30.1032	10.7892	25.9851	44.3667	6.2382	15.4956	0

Table 6 Mutual demand between points in the grid map of Shanghai

0	9.212	3.532	8.795	3.894	2.1456	4.871	8.859	5.789	1.498
62.288	0	14.723	151.482	21.394	81.884	10.417	19.429	41.499	15.79
80.532	20.756	0	19.263	149.361	96.64	17.339	9.327	33.257	8.967
76.795	112.493	26.253	0	13.901	120.377	28.924	8.936	13.006	5.297
170.894	80.394	50.125	13.901	0	76.278	30.971	42.965	12.895	38.604
3.1124	1.884	1.832	3.377	2.278	0	4.301	2.313	3.383	6.674
23.871	13.456	4.339	12.924	40.913	63.301	0	32.988	34.923	11.627
93.859	24.429	16.327	16.936	19.965	64.313	20.146	0	7.936	2.152
43.789	25.499	29.257	10.0026	12.895	59.383	41.918	9.153	0	10.125
49.498	29.793	9.966	9.297	38.614	72.674	14.613	3.639	14.291	0

Results of supply and demand matching schemes

In practice, subsidies are carried out in different regions, and the subsidy schemes in each region vary with the distribution of supply and demand. But the subsidy standard is roughly the same. In this paper, assumptions are set as follows: Huangpu District is located in "A", Baoshan District is "B", Qingpu District is "C", Jinshan District is "D", Pudong New area "E", Pudong New area central is "F", Jiading District is "G", Minhang District is "H", Fengxian District is "I", Songhui District is "J".

Distance-based transport costs between locations are as follows:

$$C_1 = p'd_{ij},$$

where p' represents the fuel cost per kilometer, and the fuel cost is 0.72 yuan/km at the time of study. Based on this formula, combined with the minimum distance between the locations in Table 6, the basic transportation cost table is obtained by MATLAB calculation (see Table 7).

First, take the freight demand of in Jinshan District 'D' as an example. On November 21, 2018, there were 25 truck drivers who did not receive orders online on the "Huochebang" platform, while there were 21 goods owners in Jinshan District released the freight demand information at the same time. This paper uses the symbol of the goods' destination to represent goods owner. Due to the influence of external

factors such as the differences of drivers, the size of trucks, the weight of goods transported, costs vary from different drivers to transport goods to the same place. The cost of each driver transporting the goods to every different destination can be calculated using MATLAB software. After importing the cost data in MATLAB, the operation of 0/1 planning assignment scheme can be calculated. When the matching scheme of vehicles and goods are obtained, the matrix of empty vehicle probability in each location in the grid can also be established. Referring to the relevant data, the personal characteristic value of drivers in Jinshan District is 0.3, and the conversion coefficient μ of the freight car driver's profit to the freight car driver's profit is 0.05. The following matrix of empty driving probability is obtained:

Combined with the results of Tables 6 and 8 and the matching result of supply and demand, the subsidy scheme for truck driver users can be obtained by corresponding to the replacement (2) of the data:

In this paper, according to the economic development level of Jinshan District, let $m_0 = 3.5$ yuan, $L_0 = 10$ km, and $p' = 0.72$ yuan/k. As the non-cash subsidy $m_3(t)$ is mainly in the form of coupons, it must be quantified before the calculation. The subsidy scheme for driver users is as follows (see Table 9):

As the formula (2) in the subsidy model is based on the possible no-load mileage of driving, the order of longer distance or higher no-load probability (that is, the destination with less demand) can be distributed more subsidies.

Table 7 Basic transport costs between locations in Shanghai (Unit: Yuan)

Place	A	B	C	D	E	F	G	H	I	J
A	0.00	21.20	5.95	42.17	28.27	1.79	11.44	16.01	31.66	20.50
B	21.20	0.00	27.16	63.38	49.47	22.99	9.76	37.21	52.86	41.70
C	5.95	27.16	0.00	36.22	22.31	4.16	17.40	10.05	25.70	14.55
D	42.17	63.38	36.22	0.00	13.91	40.38	53.62	26.17	10.52	21.67
E	28.27	49.47	22.31	13.91	0.00	26.48	39.71	12.26	3.39	7.77
F	1.79	22.99	4.16	40.38	26.48	0.00	13.23	14.22	29.87	18.71
G	11.44	9.76	17.40	53.62	39.71	13.23	0.00	27.45	43.10	31.94
H	16.01	37.21	10.05	26.17	12.26	14.22	27.45	0.00	15.65	4.49
I	31.66	52.86	25.70	10.52	3.39	29.87	43.10	15.65	0.00	11.16
J	20.50	41.70	14.55	21.67	7.77	18.71	31.94	4.49	11.16	0.00

Table 8 Value matrix of probability P_{ij} for truck load between points

0	0.2159	0.1522	0.1358	0.0717	0.1994	0.1848	0.1029	0.1946	0.1548
0.2526	0	0.1849	0.1058	0.1026	0.2164	0.0215	0.1277	0.1847	0.0213
0.2026	0.1148	0	0.0422	0.1414	0.2448	0.1954	0.1659	0.1628	0.1948
0.2154	0.1659	0.1345	0	0.1859	0.2638	0.1246	0.1243	0.1749	0.1519
0.1936	0.0594	0.1844	0.1101	0	0.2561	0.1948	0.1458	0.1348	0.1024
0.1845	0.1323	0.1172	0.2454	0.0892	0	0.1346	0.1715	0.0615	0.0641
0.2369	0.1829	0.1732	0.1347	0.2016	0.2872	0	0.1437	0.0314	0.0315
0.2423	0.1024	0.1249	0.1659	0.2019	0.2258	0.1403	0	0.0874	0.0879
0.2645	0.1176	0.1158	0.1744	0.1814	0.2426	0.1216	0.1948	0	0.1024
0.1432	0.1026	0.1624	0.0987	0.1594	0.2145	0.1048	0.1527	0.0459	0

Table 9 Driver users' subsidy program

Driver users	cash allowance $m_3(t)$ (yuan)	Non-cash subsidy $m_3(t)$ (yuan)
D1	28.74	2.3
D2	24.36	3.4
D3	18.26	5.1
D4	14.25	4.2
D5	15.17	2.5
D6	16.48	3.4
D7	14.27	4.9
D8	26.34	7.5
D9	18.44	8.4
D10	12.35	5.9
D11	17.69	4.3
D12	19.88	4.5
D13	22.64	8.3
D14	23.58	4.1
D15	27.38	6.9
D16	19.58	7.6
D17	18.34	5.8
D18	16.48	2.7
D19	28.59	4.5
D20	16.37	3.7
D21	18.34	2.6
D22	23.55	5.3
D23	25.48	5.7
D24	19.46	4.8
D25	13.49	3.7

According to formula (3), the subsidy available to the consignor user in this matching can be calculated. Therefore, here we get a table of the number of historical bars for the user's published information (see Table 10).

According to the economic level of Jinshan District, we set $\lambda = 0.125$ and replace it with formula (3). Therefore, the

subsidy scheme of the goods owner can be obtained as follows (see Table 11):

Considering that each region has different characteristics, we know that the supply and demand statuses are different even if the subsidy scheme changes, which is the characteristic of this model. Without limited fixed level subsidy amount, the subsidy scheme can achieve a shorter time to improve the platform evaluation, and it also attracts more users to use the "Huochebang" platform according to the different aspects of the driver and user.

Solution of evaluation model

1. "Vehicles hailing difficulty" index.

In the above paper, the representative of Jinshan District D is assigned to study the feasibility of this subsidy scheme. Because of geographical differences, consignor's satisfaction about the waiting time varies from region. The minimum satisfaction time of the consignor's waiting time is $T_0 = 30$ min, and the maximum satisfaction of the waiting rate is $\delta_0 = 27.26\%$. In the index of "ride hailing difficulty", the demand stimulus coefficient and supply stimulus coefficient depend on the consumption level, concept, and local economic development level and development degree of people in different regions. This paper does not analyze the process of solving specific coefficients. According to the relevant data, the demand stimulus coefficient and supply stimulus coefficient of Jinshan District are obtained as follows (see Table 12):

$k_1 \neq l_1$ and $k_3 \neq l_3$ in the Jinshan District. According to the (14) condition, even after the subsidy, supply and demand are not equilibrium. The conversion coefficients of time and no-load rate and the transformation coefficients of taxi hailing difficulties can be calculated according to the regional characteristics, as shown in the following Table 13.

In Jinshan District, before the subsidy, the supply quantity of $m_1(t) = m_2(t) = m_3(t) = 0$, the supply quantity

Table 10 Historical information published by the consignor user

Consignor users	x'_j (twig)	x''_j (twig)	p_j (yuan)	Consignor users	x'_j (twig)	x''_j (twig)	p_j (yuan)
A1	4	1	312	E2	6	5	589
A2	10	5	424	F1	11	8	488
A3	6	4	298	F2	18	15	274
A4	20	16	306	F3	14	5	346
A5	3	1	452	F4	5	2	287
A6	0	0	586	G1	6	3	467
B1	8	5	577	G2	2	2	604
B2	16	15	279	H1	7	4	482
B3	5	2	349	I1	9	6	531
C1	7	6	378	J1	11	10	273
E1	4	3	276				

Table 11 Owner user's subsidy scheme

Owner users	Cash subsidy $m_1(t)$ (yuan)	Non-cash subsidy $m_1(t)$ (yuan)
A1	9.75	4.5
A2	26.5	3.2
A3	24.83	5.6
A4	30.6	1.7
A5	18.83	4.9
A6	0	10
B1	45.07	4.2
B2	32.6	7.5
B3	17.45	4.3
C1	40.5	2.6
E1	25.87	5.4
E2	63.31	1.8
F1	76.3	2.6
F2	49.09	2.7
F3	26.56	3.7
F4	24.68	4.5
G1	50.2	5.6
G2	74.39	5.1
H1	59.21	5.8
I1	76.11	6.4
J1	53.36	6.1

Table 12 Proportion coefficient of supply and demand stimulation

Proportional coefficient of supply stimulus	Proportion coefficient of demand stimulus
$l_1 = 0.23$ $l_2 = 0.048$ $l_3 = 0.2$	$k_1 = 0.31$ $k_2 = 0.083$ $k_3 = 0.2$

Table 13 Conversion coefficients

Time conversion ratio coefficient	No-load conversion ratio coefficient	The proportion coef- ficient of difficulty Transformation of Taxi
$b_1 = 35$ $b_2 = 202.4$ $b_3 = 0.764$ $b_4 = 0.0125$	$c_1 = 0.043$ $c_2 = 0.237$	

$D_0 = 25$, the demand quantity $Q_0 = 21$, and currently the supply quantity is greater than the demand. Taking $W = 4$ into formula (15), we can get $R_0 = 5.876$. In the case that the supply quantity is greater than the demand quantity, the vehicle hailing is still difficult. The reason that orders matching need a long time is not only the lack of trucks, but also the unreasonable price and the low demand for relative destinations. Therefore, it is necessary to establish subsidy schemes to encourage drivers to response the orders.

After establishing the subsidy scheme, the gap of supply and demand after the subsidy can be predicted based on formula (9). In this subsidy scheme, the total amount of subsidy to driver users, $m_2(t)$, equals 492.32 yuan. The total subsidy amount to consignor users, $m_1(t)$ equals 825.21 yuan, and the total subsidy amount after quantification of non-cash subsidy, $m_3(t)$, equals 220.3 yuan. The value of $m_1(t)$, $m_2(t)$, $m_3(t)$ and the stimulus coefficient of supply and demand can be taken into formula (9). We can get the following:

$$\begin{aligned}
 W &= \left| (k_1 - l_1)m_1(t) + (-k_2 - l_2)m_2(t) \right. \\
 &\quad \left. + (k_3 - l_3)m_3(t) + Q_0(t) - D_0(t) \right| \\
 &= |(0.31 - 0.23) \times 825.21 - (0.101 + 0.048) \\
 &\quad \times 492.32 + (0.2 - 0.2) \times 220.3 + 21 - 25| \\
 &= 11.32 < 4
 \end{aligned}$$

Then feasibility of subsidy scheme can be judged by how the problem of "vehicles hailing difficulty" is solved. Taking the value of W and its conversion coefficients into formula (15), we can get:

Supply and demand after subsidy can be written as follows:

$$\begin{aligned}
 Q(t) &= [k_1m_1(t) - k_2m_2(t) + k_3m_3(t)] + Q_0(t) \\
 &= 0.31 \times 825.21 - 0.101 \times 492.32 + 0.2 \times 220.3 + 21 \\
 &= 271.15
 \end{aligned}$$

$$\begin{aligned}
 D(t) &= [l_1m_1(t) + l_2m_2(t) + l_3m_3(t)] + D_0(t) \\
 &= 0.23 \times 825.21 + 0.048 \times 492.32 + 0.2 \times 220.3 + 25 \\
 &= 282.47
 \end{aligned}$$

$Q(t) < D(t)$, and $T_0 = 30 > \frac{b_2}{W} = 17.87$. The degree of "ride hailing difficulty" is

$$\begin{aligned}
 R &= c_1 \max \left\{ T_0, \frac{b_2}{W} \right\} + \frac{c_2}{b_4 W} \\
 &= 0.043 \times 30 + \frac{0.237}{0.0125 \times 11.32} = 2.965
 \end{aligned}$$

Compared with R_0 , "vehicles hailing difficulty" is reduced significantly. After this subsidy, the amount of the platform users increases. Although the increase of supply is greater than demand, which makes the gap between supply and demand larger, it alleviates the problem of long waiting time for consignor users. All the results above indicate that this subsidy is meaningful.

2. Social welfare model

After using the index of "vehicles hailing difficulty" to evaluate the subsidy scheme, it is determined that the subsidy scheme can alleviate the problem in Jinshan District and the subsidy scheme can improve the development of

the platform. Then we should evaluate the impact of the platform on the society. Therefore, we also need to use the social welfare model to test whether the platform is beneficial to the society after the subsidy. The social welfare model is as follows:

$$\begin{cases} S = \sum_{i \in R} \left[\frac{p^{a+1} \cdot \alpha}{\alpha+1} \left(k_1 k_2^\beta \right)^{\frac{1}{a}} \cdot V_i^{\frac{\beta \gamma}{a}} - c \left(k_1 k_2^\beta p^\alpha V_i^{\beta \gamma} + V_i \right) \right] \\ V = \sum_{i \in R} V_i = \sum_{i \in I} E_i d_i = \sum_{i \in I} \left(\sum_{j \in J} q_{ij} \cdot \sum_{j \in J} d_{ij} P_{ij} \right) = g(m', n') = g\left(m \frac{x_1}{r_1} n \frac{x_2}{r_2}\right) \\ \alpha < -1 \end{cases}$$

In the model, $k_1, k_2, \alpha, \beta, \gamma$ are constants, which are determined by the characteristics of each region. The constants will not be explained in detail as above. $k_1 \leq 45,061$, $k_2 = 1386$, $\alpha = -1.3$, $\beta = -0.2$, $\gamma = -1$, $c \leq 1.803$, $p \leq 4.41$. m and n are the same as the θ and μ , $m \leq 0.5$, and $n \leq 0.06$.

Conclusion

In this paper, considering the use of "Huochebang" information platform without subsidies, we formulate different levels of subsidy standards based on the problems in the transaction orders of drivers and shippers on the sharing logistics platform. Moreover, according to the actual physical meaning, we consider the shortest distance from the driver's initial location to the customer's location and the demand of the freight destination, and establish the evaluation index of the total empty mileage. According to the freight cost, a dynamic matching model of freight supply and demand is established, and the different levels of freight subsidy are set up based on the freight distribution scheme. Thus, we consider the models of the influence of different subsidy policies on the use of the platform, and finally the evaluation of the effects of different subsidy policies on vehicles is established. The problem of goods matching is solved, and the optimal subsidy scheme is determined according to the evaluation results. We also establish index by considering the index of "ride hailing difficulty", which is measured by the time of the consignor waiting for the order and the empty load rate of the freight car. Therefore, the actual problems can be quantified. Finally, we establish a subsidy model based on the maximum interests of the platform and the optimization of social welfare, and take the "Huochebang" as an actual case to analyze. The study shows that the model constructed in this paper can be well applied to the subsidy problem of sharing logistics platform.

Our paper has a few limitations that provide avenues for future research. A limitation is that we formulate different levels of subsidy standards only considering the transaction orders of drivers and shippers. However, there are many factors that have an influence on the standard of

subsidy such as different regions and government intervention. We leave further exploration to future research.

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Availability of data and material The authors declare availability of data and material.

Declarations

Conflicts of interest/Competing interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

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