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An Empirical Study on the Innovation Sharing Express Box: Collaborative Consumption and the Overlay Network Design

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Abstract: Sharing express boxes is an effective disposal method for obsolete express packages. Its appearance also represents an unstoppable trend in the development of green logistics. This paper takes the sharing express box as research object and conducts two-stage research. In the first stage, the collaborative consumption theory and calculus are used to analyze the economic benefits that sharing express boxes bring to operators, that is, to demonstrate the feasibility of this business model from an economic perspective. In the second stage, the design of the overlay network is studied from the management science perspective. Firstly, an optimal coverage model is established considering the characteristics of the sharing express box, and cleaning costs, relocation costs, etc. are all integrated into the model. Secondly, the genetic algorithm is used to solve the model. A numerical example is described to illustrate the feasibility of the proposed method. In addition, sensitivity analysis investigates the effect of hub coverage change on the results. Finally, the theoretical guidance gained from this paper can be beneficial to the sustainable development of sharing express boxes.

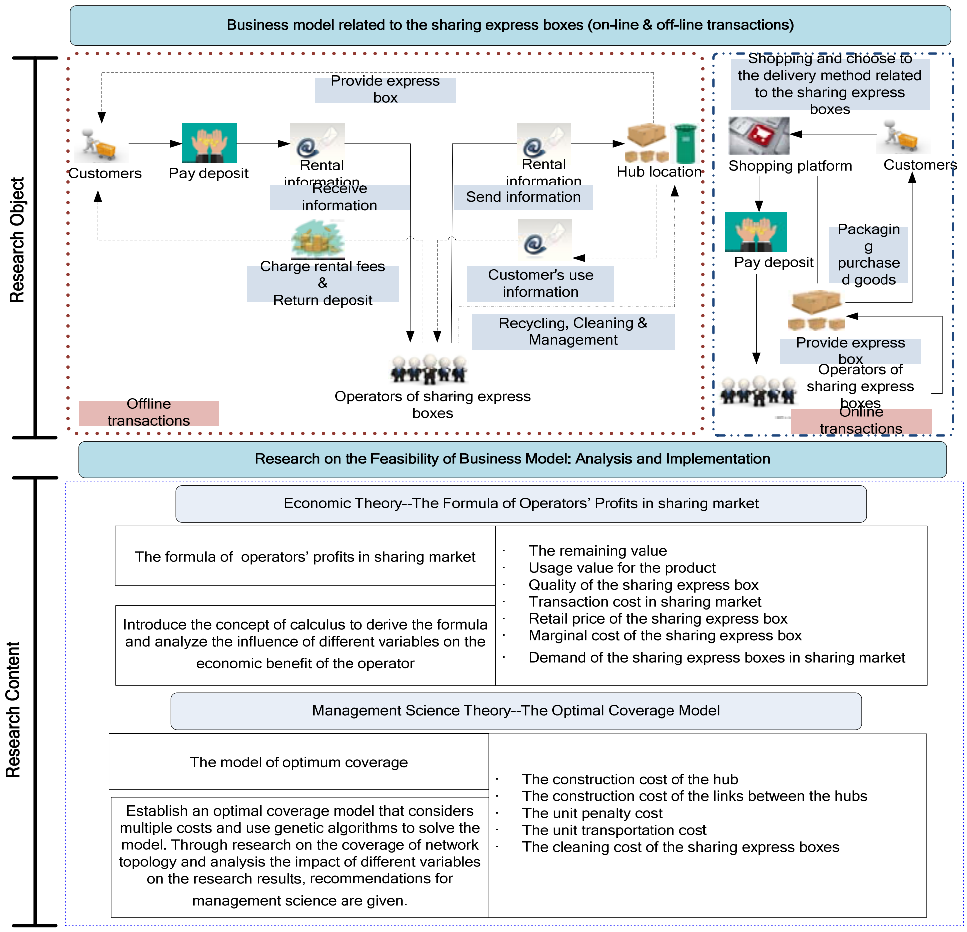
Keywords: sharing express box; collaborative consumption; overlay network design; green sharing; green innovation; sustainability

1. Introduction

As e-commerce and online shopping enter the heyday, the rapid development of the express delivery industry has brought about an increasingly harsh environment. According to statistics from the State Post Bureau, China consumed 9.92 billion crates, 6.985 billion meters of tape, and 8.268 billion plastic bags in 2015. If an estimated 0.2 kg of rubbish is produced per package, a total of more than 4 million tons of packaging waste can be generated. In 2016, the number of courier services in Mainland China exceeded 31.2 billion, and as many as 46 million tons of corrugated boxes were used. Therefore, it is important to increase the recovery rate of express packages, promote and use green packaging, and accelerate the transformation of express delivery companies to green logistics [1]. At present, many e-commerce platforms and related express companies, such as suning.com, Jingdong and Rookie League, have launched green logistics. Among them, the most talked about is the "Shared Express Box Program" launched by Suning's e-commerce company. Once launched, it was given a major mission to completely change the source of courier packaging waste. The sharing express box is a plastic express box that can be reused. It replaces the commonly used corrugated box. When it is used, it is a square plastic box. After use, it can be disassembled and folded into a square plastic board. The highlight is that it can achieve the goal of environmental protection by recycling the courier box. In addition, it also has good economic benefits. The production cost of a single shared express box is $3.9126, and the service life can be greater than 1000 reuses. The cost for the single use of each sharing express box is only $0.003913. The sharing express box explores a good solution for green logistics. Meanwhile, the sharing express box is also a new model that the company explores with market-based methods driven by environmental responsibility and corporate benefits. It relies on the original logistics system built by the e-commerce platform to ensure that the courier box is effectively recycled and reused, which effectively solves the problem of difficult recycling and reuse of packaging materials. This not only saves costs, but also saves resources and creates a win-win situation.

The sharing express box business model reflects the features of the sharing economy era, which is the product of the development of green logistics. Its main business model is as follows: the sharing express box operator cooperates with merchants and provides them with a shared express box that can be recycled many times, and the merchant pays the corresponding fee to the operator. On the other hand, consumers may choose to share the delivery method of the express box and pay the corresponding deposit to the operator when purchasing online. When customers receive the package, they remove the personal information and return it to the hubs and apply for a deposit refund. Operators regularly clean, repair, or collect shared express boxes at the hub. In addition, consumers can also rent sharing express boxes at the hub when they are spending offline (as shown in Figure 1). Obviously, the hub plays an important role in sharing the express box business model. Not only do consumers need to return the express boxes through the hub, operators also must manage the express boxes through it. Therefore, the optimum hub location is critical, which has an impact on the operator's management efficiency, but also affects the coverage to a certain extent, and then affects the degree of consumer satisfaction. Based on this, this paper takes the sharing express box as the research object and conducts in-depth research on its hub location and overlay network design on hubs.

In this research process, there are mainly the following findings: (1) From the collaborative consumption perspective, the business model of sharing express boxes is feasible. From the management science perspective, the optimal overlay model considering cleaning costs, relocation costs, construction costs of hubs, construction costs of links between hubs, and penalty of costs can be solved, so it is also theoretically feasible. In practical applications, Suning Tesco and Alibaba Group have already launched the shared express box business in China. Furthermore, the promotion of this consumption model caters to the concept of low-carbon life, which is the development direction of the express delivery industry. (2) The economics guidance for the development of sharing express boxes: the development of sharing express boxes is the inevitable result of the law of value, and it is also the choice of the market. However, to achieve its sustainable development, the government should also consider its macro-control function. For example, the government can introduce advanced foreign technologies and innovate clean production technologies. At the same time, the biodegradable material can be introduced into the express packaging industry to speed up the development and transformation of packaging technology. In addition, the government can also give tax incentives to companies that use sharing express boxes to raise awareness of environmental protection in society. (3) Guidance for management science related to the development of shared express boxes: The popularity of shared express boxes is a positive effect on the concept of low-carbon life. It effectively solves the problems of environmental pollution and waste of resources caused by obsolete express packages. However, to develop this model further, it is necessary to establish a long-term supervision and management mechanism.



Introduce the concept of calculus to derive the formula and analyze the influence of different variables on the economic benefit of the operator

Establish an optimal coverage model that considers multiple costs and use genetic algorithms to solve the model. Through research on the coverage of network topology and analysis the impact of different variables on the research results, recommendations for management science are given.

Figure 1. The operating mode of sharing express boxes and paper' structure.

This paper is structured as follows: Section 2 provides a detailed literature review on sharing express packages, collaborative consumption and hub location; Section 3 demonstrates the economic feasibility of sharing express boxes through collaborative consumption theory; Section 4 presents the process of hub location model establishment based on the principle of minimizing the overall costs; a numerical example is given in Section 5, in which the importance of the relevant variables is also considered; finally, the relevant conclusions, the research direction in the future, as well as the inadequacies are discussed in Section 6.

2. Literature Review

Literature is reviewed in three related directions: sharing express packages, collaborative consumption, and hub location.

The current research on sharing express packages mainly focuses on the following two aspects: (1) Design of express packaging and environmental impact assessment [2,3]; (2) Recycling mode of express packages [4–6]. In recent years, China's express delivery industry has developed rapidly, and the issue of packaging design and damage during transportation has received increasing attention. Based on the theory of LCA (Life Cycle Assessment), Manfredi et al. [2] studied three disposal methods for express packaging waste, namely, recycling, incineration, and landfill. The environmental performance of the three disposal methods was compared through LCA modeling. The results show that recycling and incineration are favorable disposal methods. Landfill is the most unsatisfactory choice from the environmental perspective. In terms of comprehensive environmental and economic benefits, recycling is one of the most important ways to achieve sustainable development. However, environmental and economic benefits are not always the main driving force for sustainable development, and the impact of social benefits should also be considered. Yıldız-Geyhan et al. [5] studied the social impact of different types of waste packaging recycling systems. It is found that improving the informal recycling system is of vital importance. Meanwhile, the social benefits brought by the improvement process were greater than the formal recycling system. With the rapid development of e-commerce and the continuous expansion of online shopping, the environmental protection and effective recycling issues of express packaging are widely discussed. In conclusion, after reviewing related literature on express packaging, it is found that the existing research mainly focuses on the qualitative analysis of express package recycling and environmental benefit assessment, and lacks quantitative analysis. In addition, there is less research on the recovery mode of express packages.

Collaborative consumption in sharing economics environments means that consumers (suppliers or demanders) use high-tech products such as Internet platforms and mobile phone terminals to share products or services with others based on common interests or mutual benefits, to achieve win-win results. It is a new type of consumption model. The existing research mainly includes the following three directions: (1) Qualitative research on the connotation, characteristics, development status, and trends [7–10]; (2) Research on the influencing factors of collaborative consumption behavior [11–15]; (3) Case studies on collaborative consumption behavior [16–21]. The related literature is summarized as follows. Lamberton et al. [7] defined collaborative consumption as "a system that allows consumers to enjoy the benefits of products without ownership of the product". Möhlmann [11] studied the factors affecting collaborative consumption through partial least squares path modeling and applied it to B2C (Business to Consumer) car-sharing services. The results revealed that customers' satisfaction, trust, and familiarity, as well as the cost, were the main factors. Juho et al. [12] conducted a study on the motivation of customers to participate in collaborative consumption. The results show that motivation comes from many factors, such as: activity sustainability, interest, and economic benefits. Compared with the traditional service platform, the collaborative consumption platform can bring more economic benefits to consumers because it can significantly reduce the intermediary costs. Ozanne et al. [16] took toy libraries as research subjects and found that the expected results of users participating in collaborative consumption include economic reasons, participation in "meaningful" social exchanges, and participation in the moral economy driven by thrifty values or ecological issues. In fact, in addition to economic results, collaborative consumer behavior also brings about some social outcomes, such as social capital, trust, and credit, which in turn further promote economic transactions. Albinsson et al. [17] found that sense of community belonging is not only the driving force for consumers to participate in collaborative consumption, but also the result of consumers participating in collaborative consumption. Schor et al. [18] found that repeated interactions between people in a sharing context can indeed create interactive social relationships, but this social relationship has certain limitations, that is, according to the hierarchy and social status, participants in working-class backgrounds were excluded. Ert et al. [19] researched Airbnb and found that the Airbnb platform's algorithm drove a dramatic increase in the number of favorable evaluations of the platform, and it was impossible to establish effective interpersonal trust between the landlord and the tenant. Overall, the existing research on collaborative consumption mainly focuses on qualitative analysis, that is, the analysis of factors that affect collaborative consumption behavior, and case studies on collaborative consumption lack quantitative research.

The "hub" is mainly used to distribute and collect sharing express packages, and the user traffic is unified into these hubs where consumers can get sharing express packages. Therefore, "hub location" plays a crucial role and it is also an important research content in this paper. Hub location consists of two sub-problems: (1) HSCP (Hub Set Covering Problem), and the main research is to minimize the construction cost and transportation cost under the unlimited number of hubs [22–25]. (2) HMCP

(Hub Maximal Covering Problem). Its main research content is to determine the optimum hub location and arrange the most reasonable number of hubs in the region to achieve the maximum utilization of the hub under the minimum operating costs [26–29]. In addition, in practice, many problem parameters are characterized by high uncertainty, and the research on the hub location under uncertain environments is also receiving increasing attention [30–36]. Janković et al. [26] proposed a new mixed-integer programming model to study single-capacity and multi-capacity maximum coverage problems with binary and partial coverage criteria. The experimental data show that the model has obvious advantages in the solution quality and running time significance. Zarandi et al. [25] extended the traditional maximum coverage location to a dynamic version and developed a simulated annealing algorithm to solve the problem. This study showed that the simulated annealing algorithm can solve the problem of facilities location with up to 2500 demand nodes. The key to solving the maximum node coverage problem is to find the best hub location within the area to meet the maximization of customer demands. Peker et al. [27] extended the definition of coverage and introduced the concept of "partial coverage" as a distance function. A mixed-integer programming model suitable for single and multiple partial coverage was proposed to determine the optimal hub location. The results showed that the hub is more likely to be in a larger city and farther away from another in the case of partial coverage. Mohammadia et al. [34] focused on the issue of capacity-based single distribution center coverage location in a hub network design and proposed a MIP (Mixed Integer Programming) model to solve the problem. In the traditional hub coverage problem, the coverage radius is an exogenous parameter that cannot be controlled by the decision maker. Therefore, the coverage radius is usually assumed to be fixed, but this is inconsistent with the reality. Ebrahimi-zade et al. [22] studied the hub set covering problem under changing coverage radius. A multi-period mixed integer model was established on the assumption that the construction cost and variable cost of the hub are proportional to the coverage area of the hub. Zhang et al. [30] studied the location of emergency service facilities under uncertain conditions. The research mainly included two parts. The first part established an uncertain location set cover model and transformed it into an equivalent deterministic position model by using the inverse uncertainty distribution. The second part studied the issue of maximum coverage under an uncertain environment. Pascal et al. [31] introduced the concept of robustness and probability optimization into the coverage problem of emergency service facilities. Case studies highlight the effectiveness of the proposed method. In the actual site selection problem, the demand is usually non-deterministic. Gao [32] used uncertainty theory to study the location of facilities under demand uncertainty. Firstly, the concept of evaluating network nodes and overall satisfaction was proposed. Based on the overall satisfaction level, a public and private facility location model was established. Finally, different location models were compared through case studies. In conclusion, the existing researches have been very extensive and in-depth, which lays a good foundation for the relevant research carried out in this paper.

This study makes the following contributions: (1) Research topics that advance with the times. Based on the existing research foundation and successful business models abroad, this paper combines with the rapid development of the sharing economy in China, takes the sharing express box as the research object, the operational management and the related overlay network design problems are quantitatively studied. (2) Innovative research perspective. This paper organically combines collaborative consumption theory with mathematical models. On the one hand, based on economic theories, the feasibility of the sharing express boxes proposed in this paper is verified. On the other hand, from a management science perspective, an optimization model is established to achieve the optimal coverage of sharing express boxes' stations within a region. (3) Extension of theory. This paper introduces collaborative consumption by establishing relevant mathematical formulas and uses it to demonstrate the feasibility of sharing express boxes. The calculus is also used in the analysis of mathematical formulas.

The literature review and framework of research method are shown in Table 1 and Figure 2, respectively.

Table 1. Literature review.

Classification		Literatures	Summarize
Sharing express packages	(1) Design of express packaging and environmental impact assessment	Manfredi et al. (2011); Williams et al. (2008)	The existing research mainly focuses on the qualitative analysis of express package recycling and environmental benefit assessment and lacks quantitative analysis. In addition, there is less research on the recovery mode of express packages.
	(2) Recycling mode of express packages	Chen et al. (2015); Yıldız-Geyhan et al. (2017); Schenk et al. (2008)	
Collaborative consumption	(1) Qualitative research on the connotation, characteristics, development status, and trends	Lamberton et al. (2012); Skærbæk et al. (2001); Zamani et al. (2107); Piscicelli et al. (2015)	The existing research on collaborative consumption mainly focuses on qualitative analysis, that is, the analysis of factors that affect collaborative consumption behavior, and case studies on collaborative consumption, lack of quantitative research.
	(2) the influencing factors of collaborative consumption behavior	Möhlmann (2015); Hamari et al. (2016); McKnight et al. (2002); Yannopoulou et al. (2013); Belk (2014)	
	(3) Case studies on collaborative consumption behavior	Ozanne et al. (2010); Albinsson et al. (2012); Schor et al. (2016); Ert et al. (2016); Chen et al. (2018); Zhu et al. (2017); Lamberton et al. (2012)	
Hub location	(1) HSCP (Hub Set Covering Problem)	Ebrahimi-Zade et al. (2016); Wagner (2008); Tan et al. (2010); Zarandi et al. (2013);	The existing researches have been very extensive and in-depth, laying a good foundation for the relevant research carried out in this paper.
	(2) HMCP (Hub Maximal Covering Problem	Janković et al. (2017); Peker et al. (2015); Karimi et al. (2011); Hwang et al. (2012)	

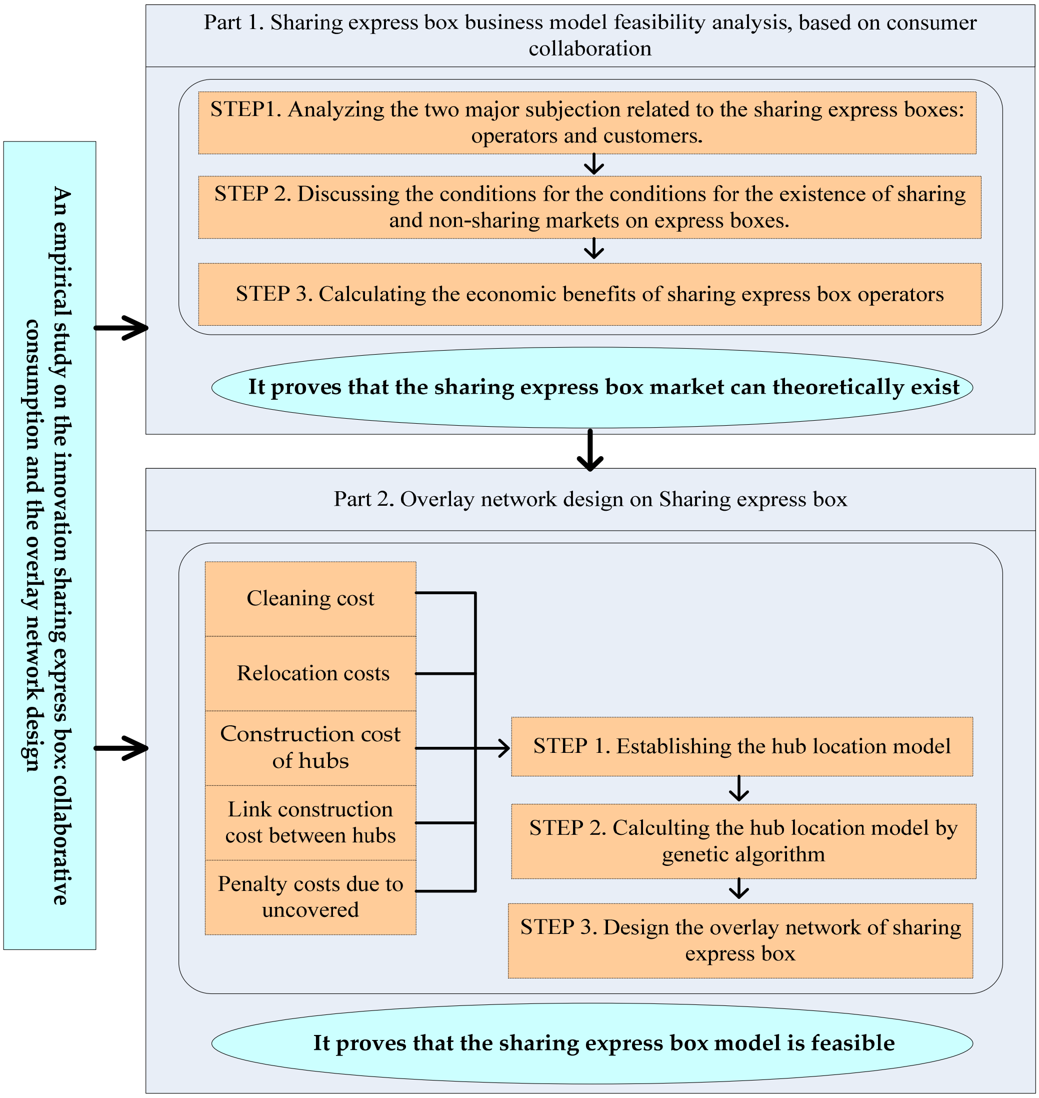


Figure 2. The framework of research method.

3. Collaborative Consumption

Sharing express box is a new type of business model-cooperative consumption mode. Its appearance is not accidental, but pokes the environmental pain point of the express delivery industry. However, due to the ambiguity of its additional costs and the unclear profit prospects, the sharing express boxes development is still at an experimental stage, and many companies are still finding their feet. Therefore, satisfying the interests of operators and customers is the key factor to promoting the successful operation of sharing express boxes, and it is also the main driving force for the rapid popularization of sharing express boxes.

This section studies the economic benefits of sharing express boxes from the view of collaborative consumption and expects to demonstrate the theoretical feasibility from an economic perspective. The research process is as follows: First, the two major subjects, operators and customers, related to the sharing express boxes are analyzed, which lays the foundation for the ensuing research. Second, based on the transaction cost and total utility, conditions for the existence of sharing and non-sharing markets on express boxes are discussed. Finally, we calculate the economic benefits of sharing express box operators to prove that the sharing express box market can theoretically exist.

The summary of notations is shown in Table 2.

Table 2. Summary of Notations.

Symbol	Description
π^s	Operators' profits in sharing market
π^n	Operators' profits in no-sharing market
p	Retail price of the sharing express box
q	Quality of the sharing express box
mc	Marginal cost of the sharing express box
ς	The remaining value
tc	Transaction cost in sharing market
$\vartheta_{ij} \sim U(0.1)$	Customers' willingness to pay the quality of express boxes
$v_{ij} = q\vartheta_{ij}$	Usage value for the product in period j as for the consumer i
β	Platform's percentage operating costs
ψ^s	Demand of the sharing express boxes in sharing market
ψ^n	Demand of the sharing express boxes in no-sharing market
m	A constant is set

Express boxes operators and customers are the two major subjects involved in this study. For operators, they specialize in express box rental and sales. The operator's profit is $\pi(p,q) = (p - mc) \cdot d(p,q)$ and $d(p,q)$ shows the demands, which is the function of the price p and the product quality q [37]. At the same time, p and q both have a positive correlation with consumer demand; that is, when the price of the product is lower, and the quality is higher, the corresponding consumer demand usually increases [38]. As for customers, they can purchase express boxes directly from the company or rent express boxes from a sharing market. If customers choose to purchase express boxes, they can also rent express boxes in the sharing market to obtain economic compensation, that is to say, it consists of two periods, the first period being the purchase, and the second period being the lease.

Before conducting a detailed study on the problem, it is assumed that customers are uniformly distributed in the rectangle of $q * q$ as shown in Figure 3. If the transaction cost (tc) of the sharing market is very high, for example: from the perspective of rational people in economics, when the transaction cost far exceeds the quality of the goods ($tc \geq q$), there is no product-sharing market. Therefore, when the total utility value of the consumer is greater than the retail price and the remaining value ($v_{i1} - v_{i2} \geq p - \varsigma$), consumers choose to purchase the express boxes. That is to say, when the $0 \leq p - \varsigma \leq q$, the operator's prices are low enough that consumers choose to buy express boxes directly instead of renting them from the sharing market typically. Similarly, when $q < p - \varsigma < 2q$, whether consumers choose to buy or rent express boxes will not have any benefits. At this point, the demand for express boxes is equal to the ratio of the blank area to the total rectangular area. As shown in Figure 3a.

$$\psi_1^n(p,q) = 1 - \frac{\frac{1}{2}(p-\varsigma)^2}{q^2} = 1 - \frac{(p-\varsigma)^2}{2q^2} \tag{1}$$

$$\psi_2^n(p,q) = 1 - \frac{\frac{1}{2}(p-\varsigma)^2 - (p-\varsigma-q)^2}{\frac{1}{2}(2q-p+\varsigma)^2} = \frac{1}{2}\left(2 - \frac{p-\varsigma}{q}\right)^2 \tag{2}$$

In the sharing market, there is a transaction cost (tc), and $(1-\beta)p_i - tc > 0$. Combining $0 \leq p - \varsigma \leq q$, $p_i > \frac{1-\beta}{tc} \geq p - \varsigma > 0$ can be obtained. According to the Formula (1), the demand can be calculated easily: $\psi_1^s = 1 - \frac{(p-\varsigma)^2}{2q^2}$. Similarly, $(2-\beta)q - tc < p - \varsigma < 2q$. Through the formula transformation, it can be obtained that $q + (1-\beta)q - tc - p + \varsigma < 0$ through the formula transformation, based on Figure 3a(1), customers surplus equals to zero, and there is no behavior of buying and renting sharing express boxes. According to the Formula (2), the demand can be calculated easily: $\psi_2^s(p,q) = \frac{1}{2}\left(2 - \frac{p-\varsigma}{q}\right)^2$. Finally, if the $\frac{tc}{1-\beta} < p - \varsigma \leq (2-\beta)q - tc$, there are transactions in product-sharing market. In addition, in this condition, the demand is as follows [37–39]:

$$\begin{aligned}\psi_3^s(p,q) \quad &= (1-p_1/q)\cdot(1-p_2/q) + (\beta p_2/q + tc/q)(1-p_1/q) + (\beta p_1/q + tc/q)(1-p_2/q) \\ &+\tfrac{1}{2}(\beta p_2/q + tc/q)(\beta p_1/q + tc/q) + (1-p_1/q)((1-\beta)p_2/q - tc/q) \\ &= 1 - \tfrac{\beta}{2(2-\beta)}\cdot\tfrac{(p-\varsigma)^2}{q^2} - \left(\tfrac{1-\beta}{2-\beta} + \tfrac{1}{2-\beta}\cdot\tfrac{tc}{q}\right)\cdot\tfrac{p-\varsigma}{q} + \tfrac{1}{2-\beta}\cdot\tfrac{tc}{q}\end{aligned} \tag{3}$$

where, $p_1 = p_2 = (p - \varsigma + tc)/(2-\beta)$ and it is the equilibrium market-clearing prices in the sharing market.

In the sharing market where there is a lease behavior, the corresponding profit of the operator is as follows:

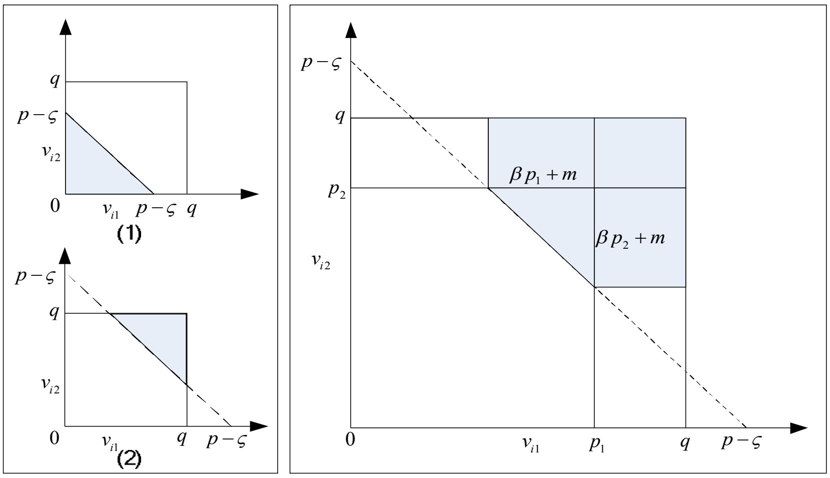
$$\pi^s = (p^s - mc)\cdot\psi_3^s \tag{4}$$

Next, analyze the economic benefits of a shared market company by introducing calculus-related theory [40–42]. Where, $\widetilde{mc} = (mc - \varsigma)/q$, $\widetilde{tc} = tc/q$ and $1/2 \leq \widetilde{mc} \leq 2$.

$$\frac{\partial \pi^s}{\partial tc} = \frac{1}{q}\frac{\partial \pi^s}{\partial \widetilde{tc}} = \left(\left((2+\widetilde{tc}) - (1+\widetilde{tc})\widetilde{mc}\right)/\left(8\left(1+\widetilde{tc}\right)^2\right)\right)\left[(1-\widetilde{mc})\widetilde{tc} - \widetilde{mc}\right] \tag{5}$$

Because $(1-\widetilde{mc})\widetilde{tc} - \widetilde{mc} < 0$, $\pi^s > \pi^n$.

Briefly, from the view of collaborative consumption, the sharing market makes the operator's profit higher than that obtained in the non-shared market. This conclusion further proves the feasibility and the rationality of the sharing express box business model, which lays a theoretical foundation for the next research.



(a) Customers'purchase decision in the no product-sharing market (b) Customers'purchase decision in the product-sharing market

Figure 3. Customers' purchase decision in different product market.

4. Hub Location and Covering Network Design under Uncertainty

In this section, the choice of sharing express box sites and the maximum coverage network design problems under an uncertain environment is analyzed by establishing relevant mathematical models. It is expected to provide theoretical guidance for the promotion of the sharing express boxes from a management science perspective.

4.1. Model Description

Based on the research of hub selection and coverage network design of sharing express boxes under an uncertain environment, this paper hopes to optimize the design to meet customer requirements. This problem can be summarized as follows: first, given a set of demand coordinate points, under the condition of uncertain demand, a total cost minimization model is established, in which the total cost is the total hub construction cost, the cleaning cost, penalty costs due to unsatisfied basic requirements of demand sites, as well as the cost of link construction between different hubs. Then, the model is solved using a genetic algorithm. Finally, the specific hub location and coverage of the network design are determined.

The objective of the model is to realize the maximum coverage of the shared express box site to meet the customer's maximum needs. The model inputs are the coordinates of the demand point, the probability distribution of the demand, the fixed coverage of the hub, the construction cost of the hub and the construction cost of the links between the hubs, the unit penalty cost, the unit transportation cost and the cleaning cost of the sharing express box. The model outputs are the specific hub locations, overlay network topology, as well as the link design between hubs.

4.2. Mathematical Model

The description of symbols in mathematical models is shown in Table 3.

Table 3. The description of symbols in mathematical models.

Symbols	Description
d_i	The demand of sharing express boxes at node i
c	Unit cleaning costs, that is, the cost of cleaning a sharing express box.
T_{ij}	Unit cost of transportation for link (i, j).
B_{ij}	The number of sharing express boxes that were relocated between hub i and j.
dis_{ij}	The distance between node i and j.
X_{ij}	Whether the link between node i and j is established.
Z_i	Whether the hub is established at node i.
f_i	The construction cost of hub i.
Fl_{ij}	The construction cost of link (i, j).
P_i	Penalty costs due to node i not being covered.
I_i	Whether the node i is covered.
N	A series of potential nodes and customers.
i, j, k	Hubs $i, j, k \in \{1, 2, \cdots, N\}$.
L	A collection of links between Hubs; $(i, j) \in L$.
Y_{ij}^k	The amount of service flowing from hub i to hub j to satisfy the service of node k.
W_i^k	The amount of service obtained by hub k at hub i.
D	The coverage of the hub.
r	The number of hubs.

4.2.1. Assumptions

(1) In the network structure, each node represents a demand center;

(2) The stations of sharing express boxes are only distributed at nodes;

(3) No more than one sharing express boxes station is assigned to a node;

(4) Assuming this network structure is a customer-to-service system model, that is, customers can go to the sharing express boxes stations to obtain services;

(5) There is no capacity limit for the connection between hubs, which means that the hubs can meet unlimited demands;

(6) All links between hubs are directed;

(7) The distance covered by the hub is equal.

4.2.2. Model Establishment

The maximum coverage solution for hub location of the sharing express boxes is represented by the following model. In addition, the objective function contains five terms: the first term is the cleaning cost; the second term is relocation costs [43–47]. Based on the uncertainty of node requirements, the sharing express box operator needs to periodically adjust the number of express boxes at hubs [48–50]. The resulting relocation costs also need to be considered, which is usually positively related to the relocation distance, relocation unit costs and relocation quantities. The third term is the construction cost of hubs; the forth term is link construction cost between hubs. The link refers to the link relationship between hubs, and the main purpose of establishing the link is to facilitate the operators to manage the hubs. The fifth term is penalty costs due to uncovered. The model minimizes the total overall cost of the five terms [51–57].

$$Min\left\{\sum_{i\in N} c\cdot d_i + \sum_{(i,j)\in L} T_{ij}B_{ij}dis_{ij}X_{ij} + \sum_{i\in N} f_iZ_i + \sum_{(i,j)\in L} Fl_{ij}X_{ij} + \sum_{i\in N} P_iI_i\right\} \tag{6}$$

Subject to:

$$Z_i + \sum_{j\in N} X_{ij} + I_i = 1\,;\ \forall i\in N,\ \forall (i,j)\in L \tag{7}$$

$$X_{ki} + \sum_{j\in N; j\neq k} Y_{ji}^k = \sum_{j\in N} Y_{ij}^k + W_i^k\,;\ \forall i,k\in N:\ i\neq k,\ \forall (k,i)\in L \tag{8}$$

$$\sum_{j\in N; j\neq k} Y_{ji}^k = \sum_{j\in N} Y_{ij}^k + W_i^k;\ \forall i,k\in N:\ i\neq k,\ \forall (k,i)\in L \tag{9}$$

$$\sum_{j\in N} T_{kj}X_{kj} + \sum_{(i,j)\in L; i\neq k} T_{ij}Y_{ij}^k \leq D;\ \forall k\in N \tag{10}$$

$$\sum_{i\in N} Z_i = r \tag{11}$$

$$X_{ij} + X_{ji} \leq 1\,;\ \forall (i,j)\in L \tag{12}$$

$$W_i^k \leq Z_i\,;\ \forall i,k\in N:\ i\neq k \tag{13}$$

$$Y_{ij}^k \leq X_{ij}\,;\ \forall k\in N,\ \forall (i,j)\in L:\ k\neq i \tag{14}$$

$$Z_i \in \{0,1\}\,;\ \forall i\in N \tag{15}$$

$$X_{ij} \in \{0,1\}\,;\ \forall (i,j)\in L \tag{16}$$

$$I_i \in \{0,1\}\,;\ \forall i\in N \tag{17}$$

$$Y_{ij}^k \geq 0;\ \forall k\in N,\ \forall (i,j)\in L \tag{18}$$

$$W_i^k \geq 0;\ \forall i,k\in N:\ i\neq k \tag{19}$$

Formula (6) demonstrates the total objective function;

Formula (7) shows the three states that may exist for all nodes in the area, such as, covered by the hub, not covered by the hub, and establishing links with other nodes.

Formulas (8) and (9) are to limit the single distribution, that is, each node can only be assigned a facility, and the amount of flow-in and flow-out service between two hubs that have established the connection relationship should be equal.

Formula (10) represents that if covered within coverage, demand points are usually completely covered by the nearest hub. However, if it exceeds the coverage radius, it cannot be covered. The coverage of each hub is equal.

Formula (11) states the number of hubs;

Formula (12) impose the links between hubs are bidirectional.

Formula (13) indicates that the node k can be covered by the hub established at node i.

Formula (14) shows that the service flow between nodes i and j can meet the demand of node k.

5. Case Study

The development of the sharing express box is a positive response to the concept of low-carbon life. Its emergence effectively solved the problem of environmental pollution and waste of resources caused by waste packaging and reflected the green development trend of logistics. However, due to ambiguous economic prospects, the development of sharing express boxes is still in its infancy and has not yet been widely used.

In this section, the feasibility of the research method is illustrated by a case study. First, 80 coordinate points are selected in region B, which is a more economically developed city in China, as shown in Table 4. Then, through a market survey and related literature analysis to obtain the required data information, we include: (1) Non-determinism: the demand at the node and the number of relocations between facilities; it is assumed that these two quantities satisfy the normal distribution, the demand meets a normal distribution with a mean of 4000 and a variance of 2000, and the number of relocations meets a normal distribution with a mean of 200 and the variance of 70. (2) Determinism: Unit relocation costs, coverage, fixed construction costs, link construction unit costs, penalties incurred without coverage, cleaning costs, and unit transportation costs. The values are: $1.8781, 5500 m, $626.0173, $62.6017, $156.5043, $0.626 and 40 m. Finally, with the aid of the operating system Windows 7.0, MATLAB, the genetic algorithm is used to calculate the overall objective function that is established in Section 4. Among that, the population size is 500, the number of iterations is 200, the crossover probability is 0.5, and the probability of mutation is 0.2.

The following series of figures shows the relevant results: Figure 4 shows the coverage of the 7 selected hubs of 80 demand points, and these hubs will provide service of sharing express boxes for the remaining 73 demand points. The blue circle in the figure indicates the demand point, the green triangle represents the selected hubs, and the red line between the node and the demand point represents the matching relationship between them. In addition, to clearly show the link relationship, Figure 5 is provided, which represents the matching of hubs and demand points. According to Figures 4 and 5, it can be clearly seen that hubs radiate services to the demand points centered on themselves, which constitutes a topology structure. Figure 6 is the link relationship between hubs and the connection relationship is bidirectional, indicating that the hubs are interconnected. Among them, the bidirectional black arrows of different hubs in the figure indicate the meaning. Based on these relationships, when a hub has insufficient inventory, the customer can seek services from other hubs. On the other hand, it also facilitates the management of operations. Figure 7 is the fitness curve, and it can be seen that after 60 iterations, the algorithm starts to converge and the fitness value approaches the optimal solution. Furthermore, sensitivity analysis is also conducted to analyze the effect of coverage with 1000 meters as a gradient and Figure 8 shows the network topology and fitness curve when the coverage is 6500, 7500, 8500, and 9500, respectively. When the number of hubs is constant, as the coverage increases, the hubs gradually shift to the right of the graph and gradually concentrate in this position. According to the model assumptions, customers go to hubs to rent the sharing express boxes. When the hubs are concentrated on the right side, the distance is far from the demand point on the left of the figure. This distribution will seriously affect the satisfaction of consumers and even cause a drop in demand. In addition, from the fitness curve, it can be seen that as the coverage increases, the distance between the average fitness curve and the optimal fitness curve increases. Overall, with the same number of hubs, blindly expanding the service scope of the hubs is unreasonable, which will cause waste of resources and affect customer satisfaction.

Table 4. Coordinate points.

	x	y		x	y
1	8147	3517	41	4387	1067
2	9058	8308	42	3816	9619
3	1270	5853	43	7655	46
4	9134	5497	44	7952	7749
5	6324	9172	45	1869	8173
6	975	2858	46	4898	8687
7	2785	7572	47	4456	844
8	5469	7537	48	6463	3998
9	9575	3804	49	7094	2599
10	9649	5678	50	7547	8001
11	1576	759	51	2760	4314
12	9706	540	52	6797	9106
13	9572	5308	53	6551	1818
14	4854	7792	54	1626	2638
15	8003	9340	55	1190	1455
16	1419	1299	56	4984	1361
17	4218	5688	57	9597	8693
18	9157	4694	58	3404	5797
19	7922	119	59	5853	5499
20	9595	3371	60	2238	1450
21	6557	1622	61	7513	8530
22	357	7943	62	2551	6221
23	8491	3112	63	5060	3510
24	9340	5285	64	6991	5132
25	6787	1656	65	8909	4018
26	7577	6020	66	9593	760
27	7431	2630	67	5472	2399
28	3922	6541	68	1386	1233
29	6555	6892	69	1493	1839
30	1712	7482	70	2575	2400
31	7060	4505	71	8407	4173
32	318	838	72	2543	497
33	2769	2290	73	8143	9027
34	462	9133	74	2435	9448
35	971	1524	75	9293	4909
36	8235	8258	76	3500	4893
37	6948	5383	77	1966	3377
38	3171	9961	78	2511	9001
39	9502	782	79	6160	3692
40	344	4427	80	4733	1112

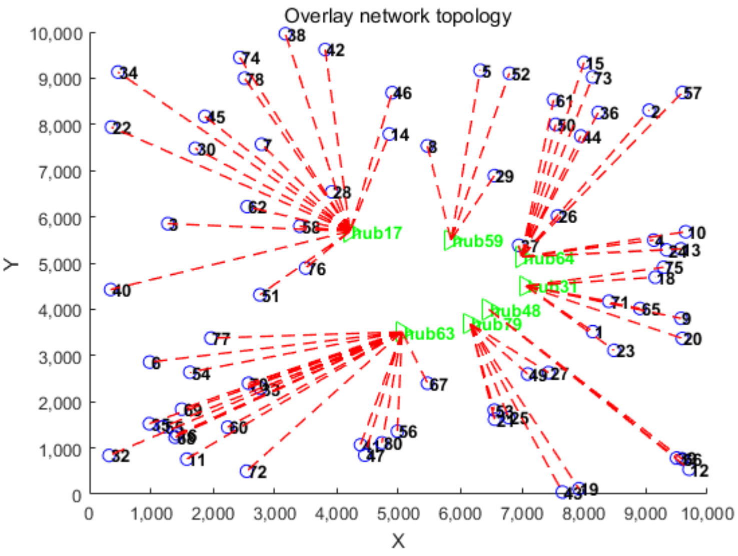


Figure 4. Overlay network topology.

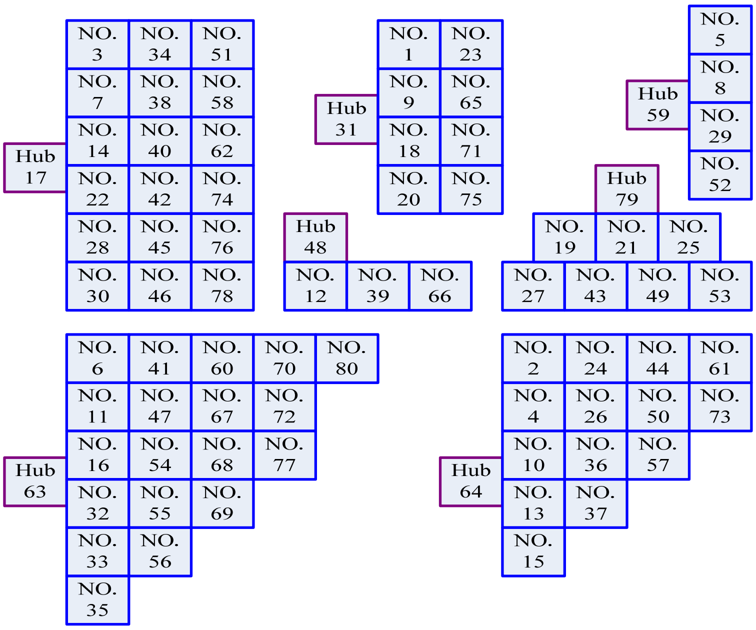


Figure 5. Matching of hubs and demand points.

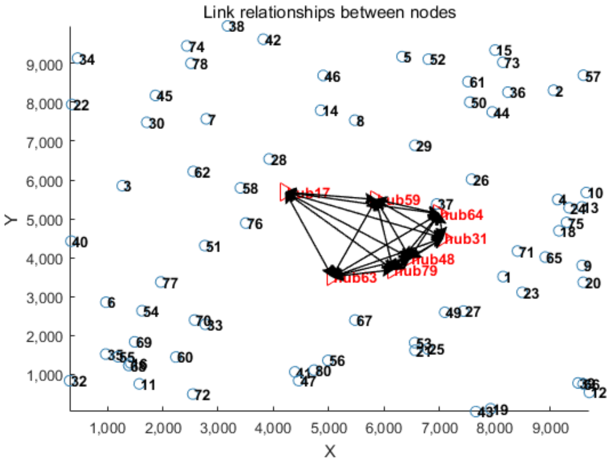


Figure 6. Link relationship between hubs.

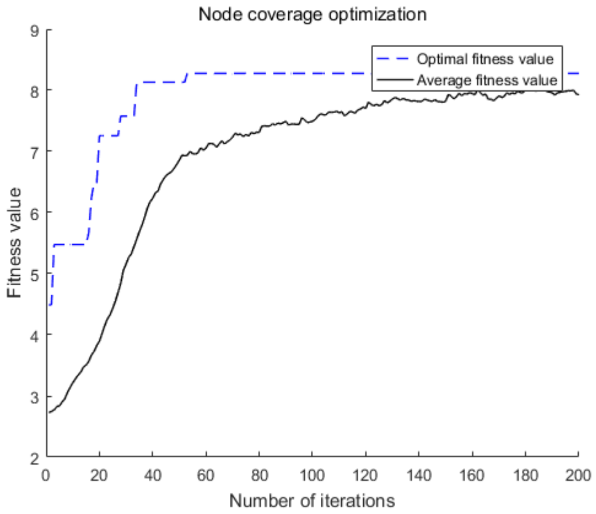
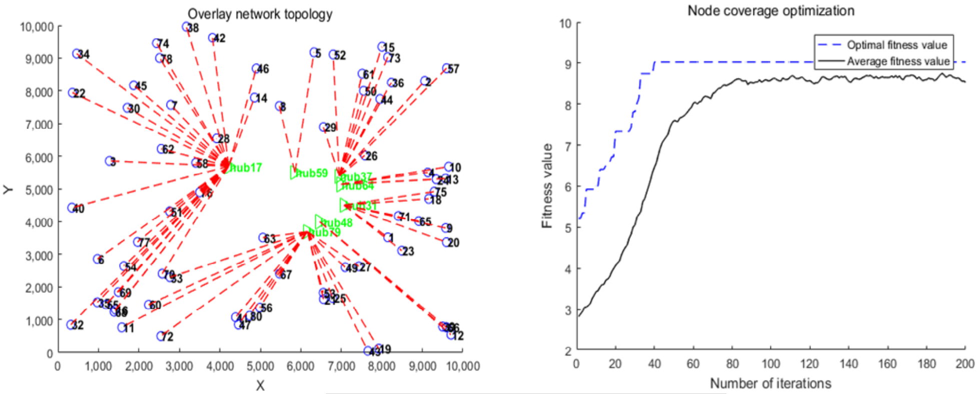
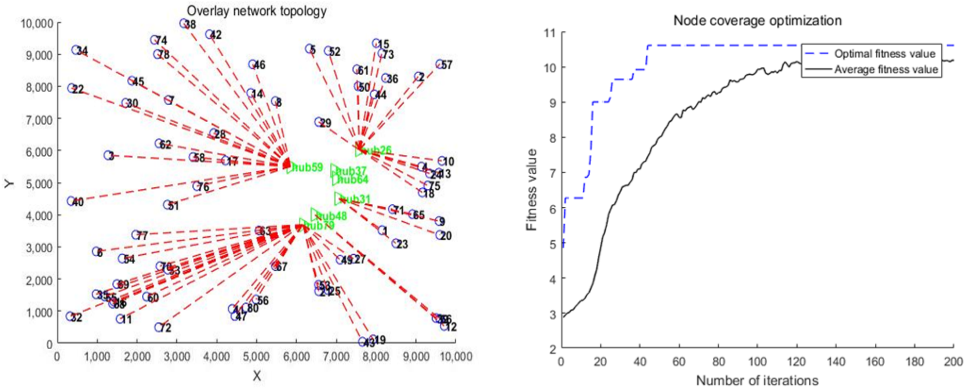


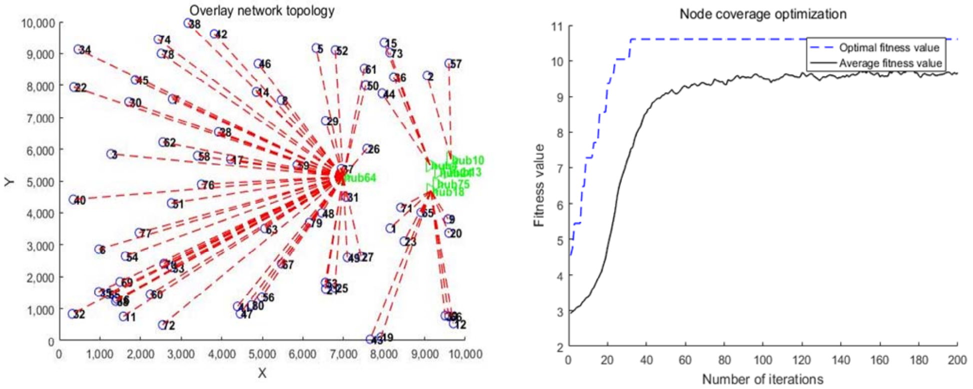
Figure 7. Fitness curve.



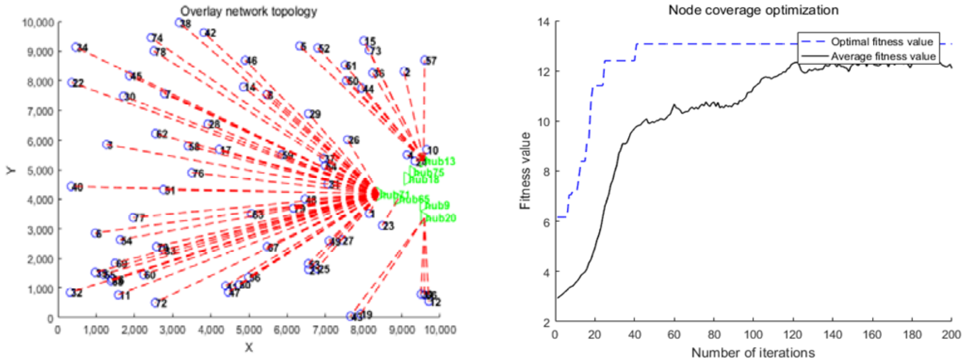
When the coverage is 6500m



When the coverage is 7500m



When the coverage is 8500m



When the coverage is 9500m

Figure 8. Overlay network topology with different coverage of hubs.

6. Conclusions

This paper combines collaborative consumption theory and hub location theory to study sharing express boxes from two aspects of economics and management science. By establishing relevant mathematical formulas and optimal coverage model, the feasibility of the sharing express box model is quantitatively analyzed and the coverage network of sharing express box is designed. Through the above research, the following management conclusions are drawn:

(1) The sharing express box business is a new type of lease economy with the characteristics of collaborative consumption. Although it belongs to the nature of leasing, it also demonstrates a new concept of trust, sharing, and green consumption. Therefore, it is necessary to strengthen scientific macro-control and credit system construction to promote its rapid development.

(2) The sharing express boxes not only realize the effective disposal of waste packaging, but also embody the concept of environmentally friendly and low-carbon life. In addition, it also improves the use efficiency of express box, and brings considerable benefits to operators. Therefore, this model is feasible.

(3) The development of the shared express box is an important manifestation of green logistics. It eases the resources and environmental pressure brought about by a large number of express packaging waste and innovates the customer′s consumption concept. From the perspective of consumption, sharing express boxes show a higher level of consumption pattern and business model, which deserves further promotion.

(4) As a concrete embodiment of the collaborative consumption model, the sharing express box is still in the initial stage of development. Its growth and maturity will inevitably meet the challenges of various private consumption patterns. Therefore, it requires the cultivation and construction of various market entities. For example, the actual delivery scale of the shared express box market is driven by capital in general, and the market plays a key role in the allocation of resources, which is the spontaneous regulation of the law of value. However, it is still necessary to join the government's macro-control to avoid the waste of resources and market confusion caused by the voluntary and blindness of market regulation.

(5) In this paper, only five items are considered in the model establishment of the optimal coverage model, such as cleaning cost, relocation costs, construction cost, link construction cost between hubs and penalty costs. Furthermore, in the sensitive analysis, the service scope is only used as a research variable to analyze its impact on the overlay network. These improvements need to be considered in the following research: ① Study the impact of the expansion of service scope when the number of hubs is not fixed, and then analyze the relationship between the number of hubs and the scope of services; ② Study the effect of other variables on the results of model changes, such as penalty costs, cleaning costs and so on; ③ Study whether reducing the coverage will have an impact on the results when the number of hubs is constant; ④ Some non-quantitative factors should be considered into our optimal coverage model, such as management level, service quality etc.

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