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Collaborative site selection study for cold chain distribution centers under low carbon policies

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Abstract: In order to solve the problem of cross-layout of cold chain logistics network and optimize the resource allocation of small and medium-sized cold chain logistics enterprises, based on the concept of low-carbon economic development and with the aim of minimizing the total cost, this paper constructs a cold chain distribution center location model including refrigeration cost and carbon emission cost from the microscopic perspective of enterprises, and selects two small and medium-sized cold chain logistics enterprises for simulation, and the simulation results show that the model can achieve the effect of saving operation cost, goods flow cost, carbon emission cost and refrigeration cost.

Keywords: Low carbon; Cold chain; Site selection; Coordination.

1. Introduction

With the development of the economy, global warming and environmental pollution and other problems are becoming more and more prominent, green low-carbon development has received worldwide attention, and our government has promulgated a series of policies to implement the concept of low-carbon economic development. The transportation industry is one of the top three sources of CO2 emissions, according to the daily carbon emission detection results of the Global Real-Time Carbon Data. As the mainstay of the transportation industry, the transformation of the logistics industry to low-carbon green development is an inevitable choice for China's economy to achieve sustainable development, while the construction of low-carbon green logistics network is a necessary means to achieve low-carbon logistics development. As an important node in the logistics network, the proper layout of the cold chain distribution center is crucial to the practice of low-carbon green economic development.

At present, the regional distribution of cold chain distribution centers in China varies widely. Market data of China's cold storage industry shows that in 2020, the number of cold storage in East China ranked first in China, up to 37.2%, and the number of cold storage in Northwest China accounted for the lowest, only 5.7%. In addition, the layout of the cold chain distribution center is also unreasonable. Information from the Cold Chain Committee of the China Federation of Materials shows that China's cold storage facilities are concentrated in the coastal area, with Shandong, Shanghai and Jiangsu ranking among the top three, while second-tier cities such as Hefei, Changsha and Taiyuan, due to the lack of cold chain distribution centers, there is often an oversupply of cold storage facilities. On the other hand, the blindness of each cold chain logistics enterprises to carry out the internal network layout of the city further intensifies the occurrence of this phenomenon, such as many cold chain logistics enterprises in a certain administrative area to cross and repeat the layout of cold chain distribution centers, while in some areas there is a shortage of cold storage, resulting in product explosion, long processing time of goods, product quality damage and other problems continue to occur. This requires a number of new and expanded cold chain distribution centers in cities with large consumption and logistics transit scale to improve the cold chain logistics network in the sales area. Then, how to choose the scientific location for the new and expanded cold chain distribution centers, not only determines the rationality of the cold chain distribution center layout, but also concerns the implementation of low-carbon policy in the logistics industry.

2. Literature Review

2.1. Cold chain distribution center siting study

Chen L and Notteboom T (2012) [1] used hierarchical analysis to determine the location of distribution centers from the perspective of value-added logistics services, considering the future expansion potential of distribution centers, labor status, and other factors. Zou, Shiao (2020) [2] et al. studied the location of cold chain distribution centers from the perspective of on-time delivery of products delivered by cold chain distribution centers, using on-time delivery rate as a constraint. Xiaohu Xing and Wenping Luo (2016) [3] considered the total refrigeration cost of product transportation from the perspective of product cargo loss and only from the macro perspective of the product of unit refrigeration cost and cargo volume, constructed a cold chain distribution center location selection model, and solved it using Lingo software. Chen, Shutong (2017) [4] and others used CPLEX to solve the impact of cargo loss and timeliness on the location of cold chain distribution centers from the perspective of combining the two dimensions of timeliness and product cargo loss.

2.2. A study of distribution center siting in light of low-carbon policies

Studies on the impact of carbon emissions on the location of distribution centers have basically focused on single logistics companies around distribution centers, and few consider the design of collaborative logistics networks among logistics companies.Gan, Weihua et al. (2020) [5] introduced indicators such as carbon emissions and time constraints in a low-carbon perspective to study O2O retail distribution centers, and solved their location options using Lingo software.Tang, Xifeng and He, J. et al. (2023) [6] used carbon emission factor as the main parameter for carbon emission calculation, established a site-path problem model with minimum carbon emission target, and invoked Cplex to solve the distribution center site selection.Lin, Teng-Sheng (2020) [7] and Martí (2015) [8] et al. study the site selection of low-carbon distribution centers under demand uncertainty. Yang Jun (2014) [9] and Abdallah T (2012) [10] et al. perform integrated optimization of siting and transportation with the aim of minimizing the total cost of siting under low-carbon policy, while Zakeri (2015) [11] constructs a network model based on carbon trading and carbon tax system to analyze the cost under two different policies of carbon tax pricing and carbon tax floating price.

2.3. References

In summary, scholars at home and abroad mainly study the location of ambient distribution centers from a low-carbon perspective, and few studies the collaborative layout of cold chain distribution centers from a low-carbon perspective. In addition, existing studies mainly consider the impact of product transportation and refrigeration costs on the location of cold chain distribution centers from a macro perspective, but in reality, there are many factors that affect the refrigeration costs of cold chain distribution centers, and the operation of cold chain distribution centers and transportation and distribution require constant temperature control to ensure the quality of cold chain products. In addition, the process of maintaining a constant temperature in cold chain distribution centers to ensure product quality generates large amounts of CO2 emissions. Therefore, this paper will consider the refrigeration cost and carbon emission cost of cold chain distribution center from micro perspective, and construct a model of cold chain distribution center location under low carbon policy, with the aim of minimizing the total cost of cold chain distribution center location, which is important for China to achieve green and low carbon development of the economy.

3. Modeling

3.1. Premise Assumptions

This paper studies a single type of cold chain whose products are all thermostatically controlled within the same temperature range, i.e. the cold chain products can be transported on the same cold chain transport vehicle and the cold chain products can be stored in the same environment.

The location of the cold chain distribution center warehouse is known, and the location of the nodes such as supply customer dealer and demand customer dealer are known.

The cold chain distribution center can transfer products from different suppliers and demanders.

A single cold chain vehicle is used and the vehicle load flow does not exceed the maximum vehicle load capacity.

No consideration of irresistible and unexpected factors and road conditions to which the vehicle is subject in the course of transportation.

3.2. Parameter Description

Given a set of supply and demand customer nodes $R=(i,j)$,Where i is the supplying node and j is the demanding node; h for the collection of urban cold chain distribution center nodes $h \in H$; c_h indicates the fixed operating cost of the urban cold chain distribution center warehouse, c_p indicates non-fixed unit operating costs; c_1 is the unit transportation cost of moving the product from the supplier node to the cold chain distribution center, c_2 is the unit transportation cost of the product from the cold chain distribution center to the demand customer. w indicates the weight value of the product, for example, w_{ih} is the weight value of the product transported from supplier i to cold chain distribution center h ; d is the transport distance, e.g. d_{ih} is the distance from supplier i to cold chain distribution center h ; c_a indicates that the company's industrial electricity unit price; q_h number of warehouse chillers; p_h capacity of warehouse refrigerating machine; t indicates the time, such as t_q indicates that the warehouse all cooling machine q running time; c_l indicates the unit cost of transport refrigeration; ς indicates the degree of vehicle insulation; θ is the heat transfer rate of the distribution vehicle k ; s_k is the thermal conductivity area of the refrigerated transport vehicle, which is calculated as the square root of the product of the external surface area and the internal surface area of the refrigerated transport vehicle, i.e. $s_k = \sqrt{s_{外}^k - s_{内}^k}$; Δtp means that the temperature difference between the inside and outside of the refrigerated vehicle is determined by the difference between the outside temperature of the vehicle and the internal temperature control of the vehicle, i.e. $tp_{外} - tp_{内} = \Delta tp$; p_e indicates the power consumption rate per cubic meter of storage space; γ is the electricity carbon emission factor; c_e is the unit transaction price of the carbon tax; s_h is the volume of storage capacity of each cold chain distribution center; y_e indicates the rate of electricity consumption per unit of product processed by the machinery and equipment; ψ indicates the carbon emission factor of the fuel consumption; f_{oil} indicates the fuel consumption per unit when the vehicle is transported fully loaded; e_{oil} indicates the fuel consumption per unit when the vehicle is transported empty; $k_{\max}$ indicates the maximum load capacity of the vehicle. x_h is the decision variable $x_h \in (1,0)$, if $x_h = 1$, it indicates that the cold chain distribution center is selected for the transfer of products, otherwise $x_h = 0$ 。 b_{hj} is the decision variable $b_{hj} \in (1,0)$, if $b_{hj} = 1$, then the demand merchant j accepts the cold chain distribution center h to deliver products, otherwise it does not accept its delivery products.

3.3. Construction of a collaborative site selection model for cold chain distribution centers under a low-carbon policy

The difference between the site selection model of cold chain distribution center under low carbon policy and the basic model of normal temperature distribution center site selection is that the cold chain distribution center needs to control the products at constant temperature to ensure the quality of the products, and the cold chain distribution center will cause some carbon emissions in the operation process. Therefore, this paper constructs the site selection model of cold chain distribution center under low carbon policy by adding the refrigeration cost and carbon emission cost of cold chain distribution center to the basic model of normal temperature distribution center site selection.

3.3.1. Basic Model for Selecting the Location of the Ambient Temperature Distribution Center

The site selection of normal temperature distribution center mainly considers the operation cost and goods flow cost of distribution center. The operation cost of distribution center is divided into fixed operation cost, such as warehouse rent, wear and tear of fixed assets, maintenance of facilities and equipment, and non-fixed operation cost, which is linearly related to the volume of goods handled, including the operation of forklift trucks, conveyors and other facilities and equipment. The flow cost of goods mainly refers to the flow cost of goods transported from the supplying customer supplier to the distribution center and from the distribution center to the demanding customer supplier, so the base model for the location of ambient temperature distribution center is:

$$I_1 = \sum_h^H c_h x_h + \sum_h^H c_p w_h x_h + c_1 \sum_{i=1}^R \sum_{h=1}^H w_{ih} d_{ih} x_h + c_2 \sum_{h=1}^H \sum_{j=1}^R w_{hj} d_{hj} b_{hj} \quad (1)$$

3.3.2. Cold Chain Distribution Center Site Selection Refrigeration Costing Model

Cold chain products are perishable, to ensure the quality of transportation and storage need strict temperature control, and cold chain products in the cold chain distribution center temperature control mainly depends on the refrigeration equipment continuous refrigeration, the use of refrigerators will increase the power consumption, power consumption is closely related to the power of the refrigerator, refrigeration time and other factors, for this reason, the cold chain distribution center refrigeration costs are calculated as follows.

$$I_{2-1} = \sum_h^H c_a q_h p_h t_q x_h \quad (2)$$

Similarly, cold chain products need to use cold chain vehicles for temperature control of products during transportation, and in this paper, referring to the research of scholars such as Ge Xianlong and Zhang Xiaoxiao (2022) [12], the heat load of refrigerated vehicles was selected as the main indicator to calculate their transportation refrigeration cost. The specific calculation formula is as follows.

$$I_{2-2} = c_l \sum_{i=1}^R \sum_{h=1}^H (1+\varsigma)\theta s_k t_{ih} \Delta t p x_h + c_l \sum_{h=1}^H \sum_{j=1}^R (1+\varsigma)\theta s_k t_{hj} \Delta t p b_{hj} \quad (3)$$

3.3.3. Carbon Emission Costing Model for Cold Chain Distribution Center Site Selection

The location of the cold chain distribution center should consider the handling of products within the distribution center, including storage and processing, as well as the cost of transporting products from the nodes served by the distribution center to the cold chain distribution center. Both of these operational aspects generate carbon emissions. Therefore, the carbon emission cost related to the location of cold chain distribution center should include the carbon emission cost of cold chain distribution center operation and the carbon emission cost of product transportation process, and the influencing factors of these two types of carbon emission cost are different, so their calculation models are designed separately below.

The carbon emission cost of cold chain distribution center operation is mainly the fixed carbon emission cost and the non-fixed carbon emission cost of cold chain distribution center warehouse. The sources of fixed carbon emission cost are mainly refrigerator cooling, warehouse lighting, etc., which are closely related to the storage area and operating hours of cold chain distribution center; the sources of non-fixed carbon emission cost are mainly the use of equipment and facilities such as packaging information system, conveyor, electric forklift, etc., which are related to the size of handled goods. Based on the above analysis, the carbon emission cost of cold chain distribution center operation is calculated as follows.

$$I_{3-1} = \sum_h^H p_e s_h t_h \gamma c_e x_h + \sum_h^H w_h y_e \gamma c_e x_h \quad (4)$$

The carbon emissions generated by the cold chain transportation vehicle are mainly from the fuel consumption of the vehicle, which is affected by many factors, such as the number of stops and starts, road congestion, poor driving, load weight, driving distance and other factors. In view of the impact of the weight of goods carried on board and the distance traveled on the fuel consumption of vehicle transportation can be better measured and controlled in the actual transportation process, this paper introduces the indicators of the amount of goods carried by the vehicle and the distance traveled to calculate the carbon emission cost of transportation of products from the supply customer to the cold chain distribution center and finally to the demand customer. The specific calculation formula is as follows.

$$I_{3-2} = \sum_{i=1}^R \sum_{h=1}^H \psi c_e \left(\frac{f_{oil} - e_{oil}}{k_{\max}} w_k + e_{oil} \right) d_{ih} x_h + \sum_{h=1}^H \sum_{j=1}^R \psi c_e \left(\frac{f_{oil} - e_{oil}}{k_{\max}} w_k + e_{oil} \right) d_{hj} b_{hj} \quad (5)$$

3.3.4. Collaborative Low Carbon Cold Chain Site Selection Model

The site selection model of cold chain distribution under low carbon policy is constructed by considering the carbon emission cost and refrigeration cost based on the traditional normal temperature distribution center site selection model with the minimum total cost as the target. The final model of cold chain distribution site selection under low carbon policy is shown below.

$$\begin{aligned}
\min &= I_1 + I_{2-1} + I_{2-2} + I_{3-1} + I_{3-2} \\
&= \sum_h^H c_h x_h + \sum_h^H c_p w_h x_h + c_1 \sum_{i=1}^R \sum_{h=1}^H w_{ih} d_{ih} x_h + c_2 \sum_{h=1}^H \sum_{j=1}^R w_{hj} d_{hj} b_{hj} \\
&+ \sum_h^H c_a q_h p_h t_q x_h \\
&+ c_l \sum_{i=1}^R \sum_{h=1}^H (1+\varsigma)\theta s_k t_{ih} \Delta t p x_h + c_l \sum_{h=1}^H \sum_{j=1}^R (1+\varsigma)\theta s_k t_{hj} \Delta t p b_{hj} \\
&+ \sum_h^H p_e s_h t_h \gamma c_e x_h + \sum_h^H w_h y_e \gamma c_e x_h \\
&+ \sum_{i=1}^R \sum_{h=1}^H \psi c_e \left(\frac{f_{oil} - e_{oil}}{k_{\max}} w_k + e_{oil} \right) d_{ih} x_h + \sum_{h=1}^H \sum_{j=1}^R \psi c_e \left(\frac{f_{oil} - e_{oil}}{k_{\max}} w_k + e_{oil} \right) d_{hj} b_{hj}
\end{aligned} \quad (6)$$

$$\sum_h^H x_h \geq 1 \quad (7)$$

$$\sum_i^R \sum_h^H w_{ih} = \sum_h^H \sum_j^R w_{hj} = w_h \quad (8)$$

$$\sum_i^R \sum_h^H w_{ih} \leq k_{\max} \qquad \sum_h^H \sum_j^R w_{hj} \leq k_{\max} \quad (9)$$

$$\sum_i^R w_{ih} \leq m x_h \qquad \sum_j^R w_{hj} \leq m x_h \quad (10)$$

$$\sum_h^H w_{ih} \geq w_i \qquad \sum_h^H w_{hj} \geq w_j \quad (11)$$

$$w_{ih} \geq 0 \qquad w_{hj} \geq 0 \quad (12)$$

where constraint (7) indicates that there must be a cold chain distribution center selected as the product transfer station; constraint (8) is to ensure that the product flow is conserved; constraint (9) indicates that the product transportation must not exceed the maximum vehicle capacity; constraint (10) has a large value of m to ensure the existence of product transportation routes; constraint (11) is to satisfy the product demand of the node. Constraint (12) ensures that the product transport flow value is positive.

4. Algorithm Design

Based on the above analysis, the model constructed in this paper is a nonlinear 0-1 mixed integer programming cold chain distribution center siting model belonging to the NP problem. Lingo software has the features of easy operation, easy language understanding and powerful functions in solving such problems [13], therefore, Lingo software is used in this paper to program the constructed model as follows.

```
min=I11+I12+I13+I21+I22+I31+I32+I33;
I11=@sum (HH(h):ch(h)*x(h));
I12=@sum (HH(h):0.2*@sum(II(i):wih(i,h))*x(h));
I13=0.5*@sum(II(i):@sum(HH(h):wih(i,h)*dih(i,h)*x(h)))+0.8*@sum(HH(h):@sum(JJ(j):whj(h,j)*dhj(h,j)*x(h)));
I21=@sum(HH(h):1.5*3*150*20*x(h));
I22=2*@sum(II(i):@sum(HH(h):(1+0.04)*2.49*5.29*tih(i,h)*24))
+2*@sum(HH(h):@sum(JJ(j):(1+0.04)*2.49*5.29*thj(h,j)*24));
I31=@sum(HH(h):0.024*sh(h)*20*0.997*0.6*x(h));
I32=@sum(HH(h):@sum(II(i):wih(i,h))*0.0022*0.997*0.6*x(h));
I33=@sum(II(i):@sum(HH(h):3.0959*0.6*((0.1736-0.0262)*wih(i,h)/2500+0.0262)*dih(i,h)*bih(i,h)))+@sum(HH(h):@sum(JJ(j):3.0959*0.6*((0.1736-0.0262)*whj(h,j)/2500+0.0262)*dhj(h,j)*bhj(h,j)));
```

5. Example Simulation

5.1. Data Preparation

There are two small and medium-sized cold chain logistics enterprises A and B in ZZ city, among which the supplier of enterprise A is i1, the cold chain distribution center is H1-H3, and the demand node numbers are 1-20; the supplier of enterprise B is i2, the cold chain distribution center is H4-H5, and the demand node numbers are 21-40. Suppose that these two small and medium-sized cold chain logistics enterprises enter into a cooperative transportation contract and need to relocate the cold chain distribution center to optimize the cost of the enterprises, and the information related to their cold chain distribution centers is shown in Table 1.

Table 1. Cold chain distribution center related data

Number	H1	H2	H3	H4	H5
Fixed Costs($)	1500	1700	1300	2000	1800
Storage area(m^3)	1500	2000	1200	2500	2000

In this paper, we obtain the location of each node through Baidu coordinate picker, and use Python to call the geopy package to calculate the distance between each node. The calculated distance from the supply node to the cold chain distribution center is shown in Table 2, and the distance from the cold chain distribution center to the demand node is shown in Table 3.

Table 2. Distance from supply node to cold chain distribution center

Number	H1	H2	H3	H4	H5
i1	26	32	21	35	25
i2	22	27	26	24	19

Table 3. (Part)Distance from cold chain distribution center to demand node

Number	1	2	3	4	5	6	7	...	33	34	35	36	37	38	39	40
H1	9	12	14	8	5	7	4	...	15	12	11	15	7	8	5	12
H2	9	14	11	16	21	13	12	...	9	7	8	5	5	16	14	4
H3	14	8	5	7	18	19	12	...	8	9	14	11	16	8	14	17
H4	14	9	10	9	5	6	4	...	10	9	12	11	6	4	16	15
H5	9	11	9	15	17	12	11	...	9	5	10	12	12	11	15	9

Since the product flow values of the supply and demand nodes are trade secrets of the companies, this paper uses random generation to generate the supply node flow values and demand node flow values of the two companies, as shown in Table 4 and Table 5, respectively.

Table 4. Supply node supply flow chart

Node number	Supply flow value
i1	6000kg
i2	6000kg

5.2. Parameter Setting

The relevant parameters in this paper were determined by reviewing relevant literature and journals, as well as web queries, as shown in Table 6.

Table 5. (Part)Demand node demand flow table

Node number	1	2	3	4	5	6	...	18	19	20
Flow value	0.53	0.04	0.04	1.23	0.06	0.55		0.11	0.08	0.16
Node number	21	22	23	24	25	26	...	38	39	40
Flow value	0.08	0.78	0.81	0.14	0.31	0.51		0.05	0.03	0.13

Table 6. List of associated parameters and facilities

Symbols	Meaning	Parameter values	Unit
c_1	Unit transportation cost of product from supplier node to cold chain distribution center	0.5	(RMB/km)
c_2	Unit transportation cost of product from cold chain distribution center to demand customer	0.8	(RMB/km)
c_p	Cold chain logistics distribution center warehouse non-fixed cost of ownership	0.2	(RMB/kg)
c_a	Enterprise industrial electricity unit price	1.5	(RMB/℃)
q_h	Number of cold chain distribution center bins with the same power chillers	3	(unit)
p_h	Cold chain distribution center warehouse refrigeration machine power	150	(kwh)
c_l	Unit transport refrigeration cost	2	(RMB/km)
p_e	Power consumption per cubic meter of storage space	0.024	(kwh/m^3)
γ	Electricity carbon emission factor	0.997	
c_e	Unit carbon tax trading price	0.6	(RMB/kg)
t_h	Cold chain distribution center cooling time	20	(H)
y_e	Power consumption of machinery and equipment to process unit of goods	0.0022	(kwh/kg)
ψ	Fuel consumption carbon emission factor	3.0959	(kg/L)
f_{oil}	Fuel consumption per unit when vehicle is fully loaded for transport	0.1736	(L/km)
e_{oil}	Fuel consumption per unit when the vehicle is transported unladen	0.0262	(L/km)

In this paper, the transportation vehicles of two cold chain logistics companies A and B are unified and integrated, and a single type of cold chain transportation vehicle is used to transport the products, and the specific vehicle-related information is shown in Table 7:

Table 7. Single cold chain transport truck related information

Foton Auzheng BJ5048XLC-FE	Parameter Symbols	Parameter Value
Maximum vehicle weight	$k_{\max}$	2500kg
Temperature difference between inside and outside the carriage when transporting the cold chain truck	Δtp	24℃
Degree of thermal insulation	ς	0.04
Heat transfer rate of distribution vehicles	θ	2.49(kcal/(h.m^2℃))
Average speed of refrigerated trucks in city traffic		40km/h
Outer compartment		5995*2250*3230(mm)
Inner compartment		3700*2100*2000(mm)

6. Analysis of Results

6.1. Comparative Analysis of Optimization Results

In this paper, we use the cold chain distribution center siting model constructed earlier to re-layout planning of cold chain distribution centers and solve it by Lingo software to get H1=1, H2=0, H3=1, H4=0 and H5=1. This shows that the optimized selection of cold chain distribution center 1, cold chain distribution center 3 and cold chain distribution center 5 as public cold chain distribution center bins can achieve the minimum total cost of location. The transportation flows after the reallocation of supplier nodes and distribution centers are shown in Table 8, and the results after the reallocation of distribution areas are shown in Table 9.

A comparison of the costs associated with the location of cold chain logistics distribution centers before and after the business synergy between the two cold chain logistics companies is shown in Table 10.

Table 8. Transportation flowchart between supplier hubs and distribution centers

Number	H1	H2	H3	H4	H5
i1	1.39	0	2.5	0	2.11
i2	1.95	0	1.55	0	2.5

Table 9. Cold chain distribution center distribution area node table

Cold Chain Distribution Center	Demand Node Number
H1	5, 6, 7, 9, 11, 12, 14, 26, 30, 31, 37, 38, 39
H3	2, 3, 4, 8, 17, 21, 22, 24, 25, 27, 33, 34, 36
H5	1, 10, 13, 15, 16, 18, 19, 20, 23, 28, 29, 32, 35, 40

Table 10. Before and after cost optimization of collaborative site selection for cold chain logistics distribution centers (Unit: $)

Name	Numerical value	Name	Numerical value	Name	Numerical value	Name	Numerical value	Name	Numerical value
Total cost before optimization	88646	Operating costs before optimization	10700	Cost of goods flow before optimization	214	Cost of carbon emissions prior to optimization	2665	Cost of cooling prior to optimization	75067
Total cost after optimization	56325	Operating costs after optimization	7000	Optimized cost of goods flow	121	Cost of optimized carbon emissions	1372	Optimized cooling costs	47832
Total cost savings	32321	Save on operating costs	3700	Saving cost of goods flow	93	Save carbon costs	1293	Save on cooling costs	27235
Percentage of total cost savings	36.5%	Percentage cost savings	34.6%	Percentage cost savings	43.5%	Percentage cost savings	48.5%	Percentage cost savings	36.3%

According to Table 10, two cold chain logistics enterprises, A and B, use the cold chain distribution center site selection model constructed in this paper to re-plan their cold chain distribution centers and carry out collaborative transportation, resulting in a total cost saving of $32,321, accounting for 36.5% of the cost saving, among which the operation cost saving is $3700; the goods flow cost saving is $93; the carbon emission cost saving is $1293; the refrigeration cost saving is RMB 27,235. The two cold chain logistics companies not only achieved cost reduction and efficiency improvement, but also actively responded to the call of the national low-carbon policy and contributed to the green development of the economy.

6.2. Conclusion

In this paper, a collaborative site selection model for cold chain distribution centers under low carbon policy is constructed with the objective of minimizing total cost, and the model is applied to simulate two cold chain logistics enterprises in ZZ City as an example. The simulation results show that the two enterprises save 36.5% in total cost, 34.6% in operation cost, 43.5% in goods flow cost, 48.5% in carbon emission cost, and 36.3% in refrigeration cost. This shows that the model constructed in this paper is scientific and reasonable. In the future, based on this model, we can consider the special characteristics of cold chain products and include constraints such as damage index and customer's expected product delivery time to make the location of cold chain distribution center more suitable for the characteristics of cold chain products and customer's demand.

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