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Research Article

Application of Collaborative Optimization in Urban Fresh Product Logistics Inventory and Distribution System

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People's requirements for material needs and living standards are gradually increasing, and consumers' demand for fresh, fruit, and vegetable cold chain foods is also increasing. This paper takes urban fresh agricultural products cold chain logistics as the research object, establishes a collaborative optimization model of urban fresh agricultural products cold chain logistics inventory and distribution based on distribution centers, proposes a partitioning solution strategy for the multidistribution center problem, and proposes a collaborative optimization in urban fresh agricultural products logistics inventory and distribution system. The application of collaborative optimization in urban fresh product logistics inventory and distribution system is proposed.

1. Introduction

In recent years, with the healthy and rapid development of China's national economy, people's requirements for material needs and living standards have gradually increased, and consumers' demand for fresh, fruit, and vegetable and other cold-chain foods has also increased day by day. With this, people's requirements for the safety and freshness of food are also getting higher and higher [1]. According to the analysis of relevant experts, it is because people pay more and more attention to food safety [2], so in recent years the public is more concerned about the safety and freshness of cold chain logistics products, and there are some products in the logistics system in the process of transportation and circulation need to be stored at low temperature and other technical means to maintain the maximum degree of freshness, nutrients, and so on; the cold chain logistics industry was born [3].

Since the establishment of the cold chain logistics system, some cold chain logistics products can be transported and sold over long distances; the seasonality of fresh fruits and vegetables in daily life has gradually become blurred; and the categories of food that people can buy in general are increasingly rich. The development of cold chain logistics benefits from the current high-speed economic situation and people's increasing demand for daily consumption, and it is foreseeable that the development prospect of cold chain logistics will be very broad in the future. In recent years, the rapid development of logistics management, facility planning, safety monitoring, and other logistics-related disciplines has led to the gradual development of the cold chain logistics industry in China [4].

There are many shortcomings in China's cold chain logistics, such as higher costs, the extremely low delivery rate of cold chain logistics and product circulation rate, very backward infrastructure, serious losses of cold chain logistics products during inventory distribution, and so on. This is mainly due to the late start of China's cold chain logistics industry compared with developed countries, the lack of reasonable cold chain logistics system planning, and backward basic logistics facilities [5]. According to professional statistics, the current loss in the process of inventory distribution due to the spoilage of cold chain logistics products has caused a large amount of irretrievable losses in the cold chain logistics industry [6]. Under the guidance of the rapid development of the global economy, China's logistics industry is rising rapidly, and cold chain logistics is also gradually attached to the relevant national departments and the entire logistics industry. The depletion of cold chain logistics products is inevitable, so the research on it to improve the cold chain logistics network can minimize the loss of cold chain products in the process of inventory distribution and then reduce the cost of cold chain logistics products, and it will also promote the economic and social development of China. Therefore, the cost of loss of goods in circulation considered in the study of the total cost of cold chain logistics network to improve the cold chain logistics network in China has now become an urgent problem [7].

Relying on the rapid development of the Internet [8], fresh product e-commerce has started to enter a golden age of development. Combined with the characteristics of perishability, easy deterioration, and high timeliness requirements of fresh products, high demands are placed on their timeliness of delivery and freshness at the time of delivery [9]. If the quality of the product is significantly degraded at the time of delivery, it will usually be rejected directly. This requires a perfect logistics system to support, through a reasonable logistics system planning to shorten the delivery time of the product, to protect the quality of the product, and at the same time can reduce the cost. With the continuous development of logistics systems and even pharmaceutical logistics systems, managers have gradually realized that there are two important decisions in logistics systems, which are inventory decisions at the tactical level and transportation path decisions at the technical operational level [10]. The two elements are interlinked and highly correlated, and inventory and distribution costs account for a large proportion of the total cost, so the backward phenomenon of benefits between the two is particularly prominent: if we hope that inventory costs are low, we need to reduce the amount of inventory, then the number of deliveries will increase, and distribution costs rise; if we hope that distribution costs are low, we need to make the number of deliveries decrease, and the amount of goods per delivery becomes larger, and then the pressure on warehouse storage becomes larger and Inventory cost increases. Therefore, in order to balance the contradiction between inventory and distribution and achieve the optimization of the logistics system, the inventory and distribution activities of this logistics network should be collaboratively optimized [11].

As the core link of cold chain logistics, inventory and distribution are mutually constrained, and changes in the decision of one link will directly affect the other link, so it is important for the long-term development of enterprises to consider the synergy of the two types of decisions [12]. Based on the existing research, this paper summarizes and refines the relevant concepts of cold chain logistics, constructs a collaborative platform for cold chain logistics supported by blockchain, ensures real-time sharing of inventory and distribution information upstream and downstream of the supply chain through the collaborative platform, focuses on the rational modeling and solution of inventory decision and collaborative arrangement of paths in the secondary network of cold chain logistics on this basis, and discusses the cold chain. It is of strong theoretical and practical significance to discuss the cooperative problem of inventory and distribution of cold chain logistics from the information technology level and business process operation level [13].

Fresh agricultural products are rich in elements and water required for life, and there are more microorganisms with life activities inside them than other products, so deterioration and corruption are the most important characteristics of fresh agricultural products [14]. The supply chain circulation is complicated and complex, mainly including raw materials, production, circulation and processing, sorting, storage, loading and unloading, distribution and sales, and so on. In the process of circulation, slight damage often causes irreversible effects on fresh agricultural products, which can lead to rapid deterioration and even corruption. Therefore, in the process of supply chain circulation, different temperatures need to be set according to the characteristics of different products such as the speed of freshness weakening to ensure product quality. Cold chain logistics of fresh products has the following characteristics compared with room temperature logistics. (1) Precise temperature control and high timeliness: cold chain logistics is more complicated compared with normal temperature logistics, mainly because the object of cold chain logistics is mainly fresh products, and the characteristics of different fresh products have big differences, and they are sensitive to the storage environment temperature, humidity, and light, so in each link of the supply chain, in order to ensure the quality of fresh products and slow down the decline of freshness, the optimal storage environment for fresh products varies greatly. In addition, fresh products have strict requirements on delivery time; cold chain logistics enterprises should deliver the products to the customer's designated location in a timely and accurate manner. Therefore, cold chain logistics enterprises need to plan the distribution path in advance to ensure timely and accurate delivery [15]. (2) More capital investment and frequent daily maintenance: fresh products have the characteristics of perishability and short life cycle and generally have extremely high requirements for temperature and humidity, so they must be equipped with professional refrigerated holding tanks and distribution vehicles in the circulation process. In the process of circulation from the upstream to the downstream of the supply chain, temperature changes are often caused by irregularities in handling and transportation operations.This can lead to the decline of product freshness, affect product quality, and cause damage to goods, which can bring huge capital losses. Therefore, it is necessary to regularly spend a lot of costs to maintain the facilities and equipment of cold chain logistics of fresh products to ensure normal temperature control of refrigeration equipment [16]. (3) Strong equipment expertise and high safety protection: in order to guarantee a constant temperature in the supply chain circulation, packaging materials with good anticollision ability and insulation capacity should be selected, and the selected facilities and equipment must also meet national standards and specifications. At the same time, to ensure product safety, safety protection is required for product information (including production date, expiration date, storage temperature, etc.), health status of distribution personnel, and cleanliness of shipping equipment [17].

Compared with ambient logistics, the main feature of the cold chain logistics operation process is the need for full temperature control of multiple products in the circulation process to delay the decay and deterioration of product freshness and ensure product quality [18]. The operation process of cold chain logistics mainly includes five links: production, storage, circulation and processing, transportation, distribution, and sales. After the raw materials of fresh products are simply processed into semifinished products at suppliers, they are packaged and sorted for transportation to distribution centers for secondary processing to become finished products, and then the products are distributed to retailers for sales, and finally, customers choose delivery or self-pickup according to their needs [19]. The basic operation process of cold chain logistics is shown in Figure 1.

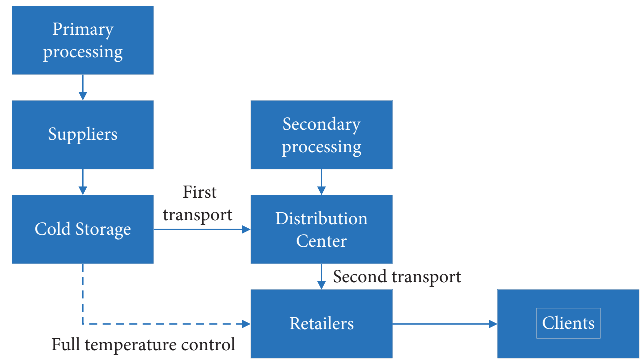

Figure 1: Basic operation process of cold chain logistics.

Collaborative cooperation of logistics enterprises refers to logistics enterprises with autonomy, which adopt unified standards and standardized processes according to certain agreements to complete partial or comprehensive third-party logistics services and play the effect that the whole is greater than the sum of its parts, with the aim of integrating scattered logistics resources and realizing intensive operation [20]. There are three types of collaborative cooperation among logistics enterprises as follows.

The first one is horizontal synergistic logistics [21], that is, the complementary synergistic cooperation among logistics enterprises with different core competencies. On the basis of constructing their own core competitiveness, enterprises choose appropriate other logistics enterprises to reduce costs through collaborative planning and operation. For example, professional transportation enterprises can cooperate with distribution centers, and the transportation enterprises can complete long-distance and high-volume mainline cargo transportation, while the distribution centers can complete activities such as storage, sorting, packaging, and distribution of goods. For enterprises that can only provide logistics services within certain regions due to capacity constraints, they can also complete the whole process of logistics activities through different distribution centers in cooperation. This collaborative approach is flexible and can realize the complementary advantages among logistics enterprises, optimize resource allocation, and enable each enterprise to develop markets and expand business while developing, as shown in Figure 2.

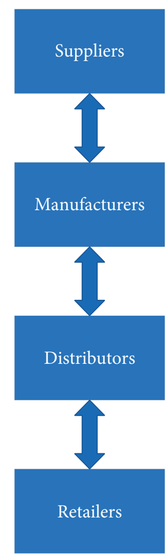

Figure 2: Horizontal collaborative logistics.

The second type is vertical collaborative logistics. Its main form is the collaboration between suppliers, producers, wholesalers, and retailers. This type of synergy can reduce the cost of each logistics enterprise and is conducive to the operational effect of economies of scale. Each logistics enterprise invests and builds together, shares the benefits, and shares the risks and costs, forming a close community of interests, which helps form a stable synergistic relationship among the enterprises. However, there are many specific details involved in the implementation process. For example, the products of different industries have different characteristics and different requirements for logistics, and how to share the expenses and costs among the participating enterprises, which makes collaborative logistics difficult [22], as shown in Figure 3.

The third type is the collaborative logistics realized by the third-party logistics. Provision of necessary logistics services by relatively independent companies. This makes the logistics service system of each enterprise faster and safer. This type of logistics operation is particularly suitable for the replenishment mode of small-lot inventory. However, in the process of third-party logistics cooperation, there are barriers to information communication and exchange of sales data, business plans, development plans, market demand, and so on. Only on the basis of the collaborative exchange of these key information can immediate, accurate, and efficient logistics services be realized and a win-win strategic state be formed [23], as shown in Figure 4.

In the area of fresh product quality losses: Donis-González et al. developed a technique to detect the internal quality parameters of the fresh product without loss of the product. The aim of the study was to detect the internal quality of the fresh product earlier in the production and processing stages of the fresh product supply chain [24]. Prakash studied the effect of ionizing radiation on fresh products and concluded that ionizing radiation has the effect of slowing down the rate of decay of freshness, prolonging the period of spoilage, and destroying bacteria [25].

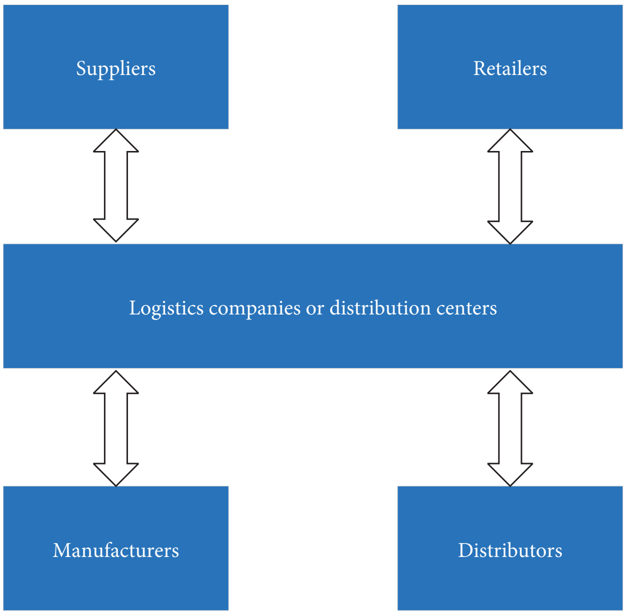

Figure 3: Vertical collaborative logistics.

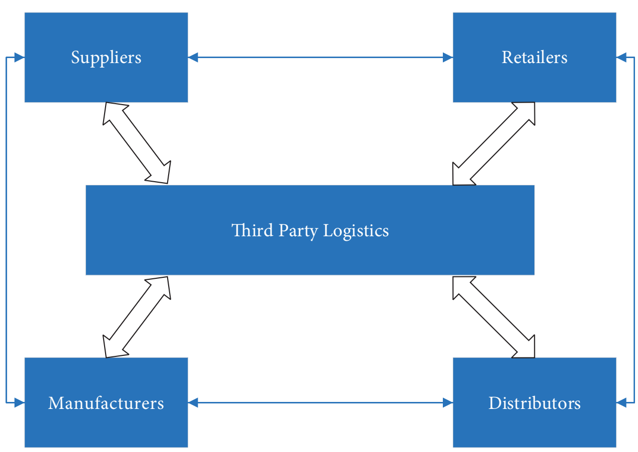

Figure 4: Collaborative logistics realized by the third-party logistics.

Ahumada et al. constructed a planning model on the stochastic allocation of fresh products based on uncertain climate and customer demand, which enables maneuvering selection risk [26]. Piramuthu and Zhao used an exponential function to represent the decaying changes in the quality of fresh product from the perspective of supermarkets and developed a model for fresh product inventory allocation by type and shelf space where demand is influenced by both product shelf display and freshness [27].

For fresh product inventory optimization research: Banerjee and Agrawal analyzed the influence of product selling price and freshness on customer demand and constructed an inventory segmentation control optimization model based on uncertain customer demand, which is only influenced by selling price before selling and determined by product freshness after starting selling [28]. Chan et al. analyzed the effect of supplier productivity on the total cost of the supply chain system and, based on this, proposed an integrated model for constructing an exponential deterioration function of a single supplier corresponding to a single retailer under uninterrupted production conditions, considering the deterioration of the product at the time of delivery and using the production quantity as one of the independent variables affecting the objective function [29]. Hsieh and Dye proposed a customer demand function based on shipment loss neutrality, shipment loss avoidance, and shipment loss finding by analyzing the theory related to reference price effectiveness and integrating reference price effectiveness with inventory control problem and constructed a dynamic pricing model based on this to pursue long-term profit maximization [30]. Nemtajela and Mbohwa reviewed the relationship between FMCG inventory control problems and uncertain customer demand by analyzing the impact of uncertain customer demand on inventory control [31]. Mirzaei and Seifi developed an inventory path optimization model based on freight cost, inventory cost, and cost of goods lost on sale and designed a meta-heuristic algorithm by combining simulated annealing and taboo search [32]. Li et al. studied a demand-dependent and dynamic pricing inventory level model [33].

In the study of inventory and distribution synergy optimization, Anily Federgruen studied a secondary logistics system consisting of distribution centers and multiple retailers and constructed an optimization model to minimize the total cost of the inventory/distribution secondary system by analyzing the inventory and distribution cost of distribution centers and the inventory of each retailer. The solution process is mainly: firstly, the actual demand of each retailer is determined and summed, then the group distribution is carried out according to the design demand of each retailer, and finally the optimal inventory control strategy of the distribution center and the optimal replenishment strategy of retailers are determined [34]. In another paper, she studied a secondary system consisting of a single distribution center and multiple retailers; considered a retailer cost minimization model including inventory holding, fixed order, and transportation costs with a determined sales rate of goods, a limited load of distribution center vehicles, and no time window; and finally verified the feasibility of the model by a heuristic algorithm [35]. Monthatipkul and Yenradee developed an optimization model based on integer programming for a single distribution center and many retailers to determine the optimal inventory control strategy and distribution strategy for the distribution center. Through comparison and analysis, this algorithm was proved to be superior [36].

In terms of multidistribution center vehicle path optimization research, Laporte established a multidistribution center path shortest model based on the shortest distribution center single vehicle type and finally verified the feasibility of the model by genetic algorithm calculation example [37]. Nagy and Salhi established a multidistribution center multivehicle model based on multiple vehicle models and solved it with a genetic algorithm based on the shortest transport distance model [38].

Lack of fresh product spoilage preservation inputs and quality change related studies: in the theoretical studies related to fresh product spoilage, there is more literature on the study of the relationship between time and freshness, but it ignores the effect of the input of preservation cost on the freshness function, which is a binary continuous function about time and preservation cost. At the same time, most of the existing literature have fragmented the relationship between freshness function and quality change function. Most of the literature treat quality change rate as a fixed parameter value; quality change does not happen overnight; it increases with the decay of freshness; quality change is a continuous process; and when the quality change rate reaches a specific value, it causes product spoilage and deterioration. Low degree of synergistic optimization of inventory and distribution: in the study of synergistic optimization of inventory and distribution, the research on each link of the supply chain is more extensive and comprehensive, among which there are relatively more studies on inventory management control and vehicle path planning, but most of the theories only focus on one of the links of the research, so independent research on each link can only achieve local optimization, which is not conducive to maximizing the overall benefits of the system. Although some scholars have proposed the relationship between the quality change function and the product freshness function based on the deterioration rate obeying the three-parameter Weibull distribution, the research is on the integrated inventory model of the three-level system of the supply chain, and the research on the path planning of the distribution vehicles and the multidistribution center problem is missing [39]. Multidistribution center problem: the current research about the supply chain secondary system is limited to the inventory and distribution from a single distribution center and a single commodity, and there is less research about the scheduling problem of multiple distribution centers, multiple yards, and multiple models.

In the operation of the cold chain logistics system, the secondary cold chain logistics network consisting of distribution centers and retailers is the object of study. In a certain period of time, considering the freshness of fresh agricultural products, the distribution center will deliver the products to the retailers according to the optimal distribution path with the optimal quantity and number of times and pursue the process of minimizing the total cost of inventory and distribution. The process of minimizing inventory and total cost of distribution: specifically, within the ordering cycle of the distribution center, the best replenishment quantity and number of replenishment times of each retailer are determined, and the best distribution path from the distribution center to each retailer is determined on this basis so that the total cost of inventory and distribution cost of the distribution center and the total cost of inventory of the retailer are finally realized. In the secondary system center of urban fresh year agricultural products cold chain logistics, if the minimization of distribution center inventory cost is pursued, it will lead to the reduction of the volume of distribution and the increase of the number of deliveries, which indirectly increases the distribution cost of the distribution center. Similarly, the minimization of the most sought-after distribution costs will lead to an increase in the volume of distribution and a decrease in the number of deliveries. The increase in the volume of distribution leads to an increase in the inventory of retailers within a certain period of time, and the inventory holding costs and freshness costs also increase, while the order quantity of the distribution center increases to meet the scale effect pursued by the volume of distribution, leading to an increase in the inventory costs of the distribution center. In short, the relationship between inventory cost and distribution cost is mutually influential and restrictive. By analyzing the relationship between inventory cost and distribution cost in the secondary system of urban fresh agricultural products cold chain logistics under the consideration of freshness cost input, it is determined that the main objects of the synergistic optimization of fresh agricultural products cold chain logistics inventory and distribution are the order quantity of distribution center, the number of delivery times and delivery quantity of each retailer, and the distribution path.

2. Collaborative Optimization Model

Urban cold chain logistics II system is a logistics network based on business flow, logistics, and capital flow with full temperature control. In addition to the functions of sorting and distribution of conventional logistics distribution centers, fresh agricultural products distribution centers also have the functions of fresh products circulation and processing, refrigeration and freshness preservation, fresh packaging, and so on. Therefore, cold chain logistics distribution centers on how to improve refrigeration technology and freshness preservation level, expand radiation radius, and realize cross-regional distribution and other issues have become the focus of research. Therefore, this paper takes the secondary system of urban fresh agricultural products cold chain logistics composed of N distribution centers and M retailers as the research object and firstly determines that the paper constructs a collaborative optimization model of inventory and distribution based on a single distribution center. Secondly, based on the single distribution center inventory and distribution co-optimization model, the thesis proposes a solution strategy for the multidistribution center problem, which is mainly based on partition processing to realize the conversion of multidistribution centers into single distribution centers for a solution.

Freshness, as an important characteristic of fresh agricultural products, is an irreplaceable factor that influences consumers to purchase fresh products, so the demand for fresh agricultural products of retailers must consider the influence of product freshness. As the freshness of fresh products decreases over time, the market demand decreases in line with the actual situation, that is, the fresher the fresh product is, the higher the demand is, so the market demand is positively related to the freshness of the product. In addition to the influence of product freshness on demand, the selling price also has an influence on demand, and the selling price has an inverse relationship with demand. Referring to the defined equation of the function in the literature on the relationship between product freshness, product selling price, price elasticity, and market demand, the demand function in this paper is derived as follows:

$$D_{ij}(t) = \left(A_{ij} - c_j P_j\right) \bullet \varphi_{ij}(t), \tag{1}$$

where $D_{ij}(t)$ is the demand for product j by retailer i at time t; A_{ij} is the potential market share, which is the maximum rate of demand for product j by retailer i; P_j denotes the product the selling price of product j; c_j is the price elasticity of demand ($c_j > 1$); and$\varphi_{ij}(t)$ is the product freshness function. When product freshness φ_{ij} tends to 0, regardless of how the product sales price is adjusted, the market demand D_{ij} also tends to 0. When the product freshness and price elasticity is certain, the market demand D_{ij} decrease with the increase in sales price P_j.

Based on the freshness model and the inventory level equation, the retailer's inventory level as a function of time is calculated by integration, as follows:

$$I_{ij}(t) = \frac{c_j P_j - A_{ij}}{\left(\alpha_j - \lambda_{bj}\right) \bullet \ln\ \theta_{bj}} \bullet \left[e^{\theta_{bj}^{\left(\alpha_j - \lambda_{bj}\right)t} - \theta_{bj}^{\left(\alpha_j - \lambda_{bj}\right)\frac{\omega_{ij} \bullet T}{n_{ij}}}} - 1 \right], \tag{2}$$

where $I_{ij}(t)$ is the inventory level of retailer i of product j, α_j is the freshness decay coefficient under normal condition of product j, λ_{bj} is the seller's investment factor for product j preservation, θ_{bj} is the initial freshness of the j product at the vendor, ω_{ij} is the replenishment cycle, and n_{ij} is the number of times the distribution center delivers product j to retailer i in an ordering interval.

During the replenishment interval, for the freshness cost of product j at retailer i, which is mainly expressed as the freshness cost, FC_1, invested in the product by the retailer to ensure the freshness of fresh agricultural products, the freshness cost is can be calculated as follows:

$$FC_1 = b_{bj} \bullet Q_{bij}, \tag{3}$$

where b_{bj} is retailer's cost of freshness per unit of product j and Q_{bij} is the number of j products per retailer i purchase. For the cost of goods loss, DC_1, it is mainly due to the cost of spoilage caused by the deterioration of fresh products as the freshness of the product decreases and the rate of spoilage increases over time after arrival at the retailer, as shown in the following equation:

$$DC_1 = \left(Q_{bij} - D_{ij}^{\omega_{ij}}\right) q_j, \tag{4}$$

where $D_{ij}^{\omega_{ij}}$ is the effective demand for product j by retailer in the ww-th replenishment cycle and q_j is the cost of goods loss per unit of fresh product j. Retailers' inventory holding costs, HC_1, are mainly the costs incurred by retailers in storing and maintaining fresh agricultural products for a certain period of time, according to the following equation:

$$HC_1 = C_{bj} \bullet I_{bij}, \tag{5}$$

where C_{bj} is the retailer's inventory holding cost for unit j product and I_{bij} is the weighted inventory for retailer i and product j. In a replenishment interval, the total cost, TC_{ij}, incurred for the product at retailer i, including the cost of freshness, the cost of damage to goods, and the cost of holding inventory, can be calculated as follows:

$$TC_{ij} = FC_1 + DC_1 + HC_1. \tag{6}$$

Assuming that retailer i replenishes fresh product j to the distribution center, the change of inventory level in the distribution center is only affected by the loss of product spoilage in the interval between replenishment periods, so the expression of the change of inventory level in the distribution center at time t is shown in the following equation:

$$I_{dijdij}^{\omega_{ij}}(t) = \left(Q_{bij} + Q_{dij}^{\omega_{ij}+1}\right) \bullet e^{\theta_{dj}^{\left(\alpha_j - \lambda_{dij}\right)t} - \theta_{dj}^{\left(\alpha_j - \lambda_{dij}\right)\frac{\omega_{ij} \bullet T}{n_{ij}}}}, \tag{7}$$

where $I_{dijdij}^{\omega_{ij}}(t)$ is the inventory level of the distribution center for retailer i of product j at replenishment interval; ω_{ij}, Q_{dij} and Q_{bij} are distribution center, retailer i for each purchase of product j in volume; λ_{dij} is the distribution center's investment factor for product j preservation; and θ_{dj} is the initial freshness of the j product at the distribution center.

In the ordering cycle T of the distribution center, for the procurement cost of product j distributed by the distribution center for retailer i, it is mainly expressed as the sum of the fixed order cost and purchase cost paid by the distribution center to the fresh product supplier, and the procurement cost, BC, is shown in the following equation:

$$BC = h_0 + h_j \bullet Q_{dij}^1, \tag{8}$$

where h_0 is fixed order cost per order for all products and h_j is unit cost per order for product j.

In the distribution center ordering cycle T, for the distribution center to deliver product j at retailer i, the inventory holding cost is mainly expressed as the cost of storage and storage of fresh agricultural products at the retailer in the distribution center, that is, the storage and storage cost, HC_2, of product-weighted inventory in the ordering cycle can be calculated as follows:

$$HC_2 = C_{dj} \bullet \sum_{\omega_{ij}=1}^{n_{ij}} I_{dij}^{\omega_{ij}}. \tag{9}$$

The freshness cost, FC_2, incurred by the distribution center when the distribution center delivers product j to retailer i during the distribution center's ordering cycle T can be calculated as follows:

$$FC_2 = b_{dj} \bullet Q_{dij}^1. \tag{10}$$

In the ordering cycle T, other than $n_{ij} \bullet Q_{bij}$ which is the fresh product that supplied by distribution center j to retailer i, the remaining fresh product will be spoilage depletion, so the cost of spoilage goods loss, DC_2, for the distribution center can be calculated as follows:

$$DC_2 = \left(Q^1_{dij} - n_{ij}\bullet Q_{bij}\right)\bullet q_j. \tag{11}$$

In addition to the completion of storage, the products in the distribution center also involve a number of other businesses. The relatively fixed costs arising from these business links are additional costs, which mainly include the costs arising from loading and unloading, distribution processing, packaging, sorting, and other business links. The amount of additional costs is mainly affected by the amount of products purchased by the distribution center. In the ordering cycle, the additional costs are mainly caused by the first replenishment period and the initial inventory of the distribution center, that is, the order quantity of the distribution center, so the total additional costs, AC_2, can be calculated as follows:

$$AC_2 = \sum_{i=1}^{N}\sum_{j=1}^{N} C_0 Q^1_{dij}\bullet x_{ij}, \tag{12}$$

$$x_{ij} = \begin{cases} 1 & \text{Distribution center replenishes product } j \quad j = 1, 2, \ldots \\ 0 & \text{Do not need replenishment product } j \quad j = 1, 2, \ldots \end{cases}, \tag{13}$$

where C_0 is the additional cost per unit of product, that is, the total cost of packaging, sorting, distribution processing, handling, and transportation per unit of product.

In this paper, one distribution path planning is modeled as an example within one ordering interval T of a distribution center. In the retailer's one replenishment interval, the distribution cost is mainly generated by the transportation link, and the transportation cost will vary depending on the transportation distance and the number of transports. For the convenience of modeling, the transportation cost in this paper includes transportation variable cost and fixed cost, and vehicle driver cost. The fixed cost, FC_3, generated by the distribution center vehicle for one delivery to the retailer can be calculated as follows:

$$FC_3 = S\sum_{y=1}^{Z}\sum_{i=1}^{N} X^y_{di}, \tag{14}$$

$$X^y_{di} = \begin{cases} 1 & \text{vehicle y provides delivery service } i = 1, 2, \ldots \\ 0 & \text{Do not provide delivery service} \quad i = 1, 2, \ldots \end{cases}. \tag{15}$$

For the variable cost of transportation, which is mainly affected by the distance from the fresh product distribution center to individual retailers, the variable cost, VC_3, of transportation during the planning period can be calculated as follows:

$$VC_3 = S_1\sum_{y=1}^{Z}\sum_{i=1}^{N}\sum_{k=1}^{N} d_{ik} Y^y_i X^y_{ik}, \tag{16}$$

$$Y^y_i = \begin{cases} 1 \text{ Provides delivery service for retailer} \quad i = 1, 2, \ldots \\ 0 \text{ Do not provide delivery service for retailer } i = 1, 2, \ldots \end{cases}, \tag{17}$$

$$X^y_{ik} = \begin{cases} 1 & y \textit{ vehicle move from i to k} \quad i, k = 1, 2, \ldots \\ 0 & \textit{vehicle do es not move} \quad i, k = 1, 2, \ldots \end{cases}. \tag{18}$$

The vehicle driver cost, DC_3, represents the sum of the costs incurred by the driver driving the vehicle to complete the delivery of all retailers on a route and return it to the distribution center during the order cycle, as shown in

$$DC_3 = S_2\sum_{y=1}^{Z}\sum_{i=1}^{N} X^y_{di}, \tag{19}$$

where d_{ik} is the distance from node i to point k in the distribution network, S is the fixed start-up costs per vehicle per delivery, S_1 is the unit transportation cost, and S_2 is the driver's labor cost per drive to deliver. In summary, the total cost incurred in the distribution chain during an ordering period in the distribution center, that is, the distribution cost objective function, can be calculated as follows:

$$\min TC_3 = \sum_{y=1}^{Z}\sum_{i=1}^{N} X^y_{di} + S_1\sum_{y=1}^{Z}\sum_{i=1}^{N}\sum_{k=1}^{N} d_{ik} Y^y_i X^y_{ik} + S_2\sum_{y=1}^{Z}\sum_{i=1}^{N} X^y_{di}. \tag{20}$$

In the urban fresh agricultural products cold chain logistics system, it is often difficult for a single distribution center to supply the demand for fresh products from supermarkets in the region, and the multidistribution center supply mode appears to meet the demand for fresh products from supermarkets radiating throughout the region. To this end, this section will propose a multidistribution center solution based on the single-distribution center inventory and distribution cooperative optimization model constructed above. At present, the solution methods for the multidistribution center problem include the partition processing method and the combinatorial optimization method, in which the partition processing method is to partition the retailers according to the distance between the distribution center and the retailers, and different regions are served by different distribution centers to realize the transformation of the multidistribution center distribution problem into a single-distribution center distribution problem for solving. The combinatorial optimization method converts the multidistribution center problem into a complex combinatorial optimization problem and realizes the multidistribution centers to provide services for retailers.

The multidistribution center combination optimization problem is computationally tedious and has harsh adaptation conditions, which are not suitable for the solution strategy of this paper. Therefore, this paper chooses the solution strategy of partitioning the retailers so as to transform the multidistribution center problem into a single-distribution center problem. At this stage, there are many kinds of partitioned distribution methods, mainly the mid-pipeline partitioning method, the scanning partitioning method, center of gravity partitioning method, and so on. The mid-pipeline partitioning method is to partition the retailers through the heavy vertical line of each distribution center connection, which is only applicable to two distribution centers distributed on the same line; scanning partitioning method is to use a kind of successive approximation method for partitioning, which is exponentially increasing and not easy to choose. The center of gravity partitioning method uses the center of gravity of all distribution centers and the line connecting the midpoints of two neighboring distribution centers to partition.

According to the constructed cooperative optimization model of urban fresh agricultural products cold chain logistics inventory and distribution, it is known that the cooperative optimization model consists of the inventory minimization model of the cold chain logistics secondary system and the distribution minimization model, which are interrelated and mutually synergistic, so the model solution algorithm is determined as a two-step cooperative process. Firstly, under the objective function of minimizing the total inventory cost of the cold chain logistics secondary system, the optimal order quantity, distribution quantity, and distribution times are determined in the distribution center. Then, based on the optimal replenishment strategy, the optimal distribution route is solved under the condition that the system distribution cost is minimized, so this paper involves the problem of inventory management control (IMC) and path optimization (PO).

In this paper, a genetic algorithm is used to solve the system inventory cost model. The genetic algorithm is mainly used for optimization problems or discrete problems where the objective function cannot be derived and has strong robustness. The objective function of the secondary system inventory in this paper is designed with numerous constraints, which is difficult to derive, and the approximate optimal solution of the objective function may have certain dispersion, so the genetic algorithm is used to solve this paper.

For PO problems with small computational effort, they can be solved by using Dijkstra's algorithm, branch delimitation, and dynamic programming. The fresh product cold chain logistics distribution optimization model in this paper involves multiple retailers and multiple vehicles, and the model computation will explode exponentially with the increase of relevant parameters. Therefore, the solution methods for such problems mainly include ant colony algorithm, particle swarm algorithm, and simulated annealing method. In this paper, we mainly solve the path optimization problem based on the strong search ability of the ant colony algorithm. Therefore, the collaborative optimization solution flow is shown in Figure 5.

Based on the collaborative optimization model of fresh product cold chain logistics inventory and distribution, this paper adopts a genetic algorithm and an ant colony algorithm to solve the collaborative optimization model. Firstly, we use a genetic algorithm to solve the objective function of minimizing the total cost of secondary system inventory and calculate the optimal number of replenishment, replenishment quantity, and the total cost of minimum inventory for retailers.

The genetic algorithm first generates a random set of the initial population, then calculates the fitness value of individuals in the population using the fitness function transformed by the objective function, and then evaluates the merits of all individuals in the population according to the calculated fitness value, in which the unqualified individuals are selected, crossed, and mutated to produce new individuals, and the new individuals form a new population and continue to iterate repeatedly.

Combining the genetic algorithm solution process and the collaborative optimization model of urban fresh product cold chain logistics inventory and distribution constructed in this paper, the genetic algorithm is designed to meet the cold chain logistics secondary system inventory optimization model, which mainly includes the design of the following links: coding, population initialization, fitness function determination, selection operator, crossover operator, variation operator, and algorithm end rule.

The ant colony algorithm is a bionic algorithm based on the ability of ants to secrete pheromones on the paths they pass through during foraging to achieve mutual communication with other individuals. From the starting point to the end point, other ants are attracted to move to that path by secreting pheromones. As the ants increase, the amount of hormones on the short path becomes more and more, leaving less hormones on the long path. Therefore, the more ants after that choose the path with a greater concentration of pheromones the greater the probability, and vice versa, the smaller the probability.

In the ant colony algorithm of this paper, let there be m ants and n cities, and the state transfer probability of the k-th ant moving from city i to city j at moment t is P_{ij}; the specific algorithm is

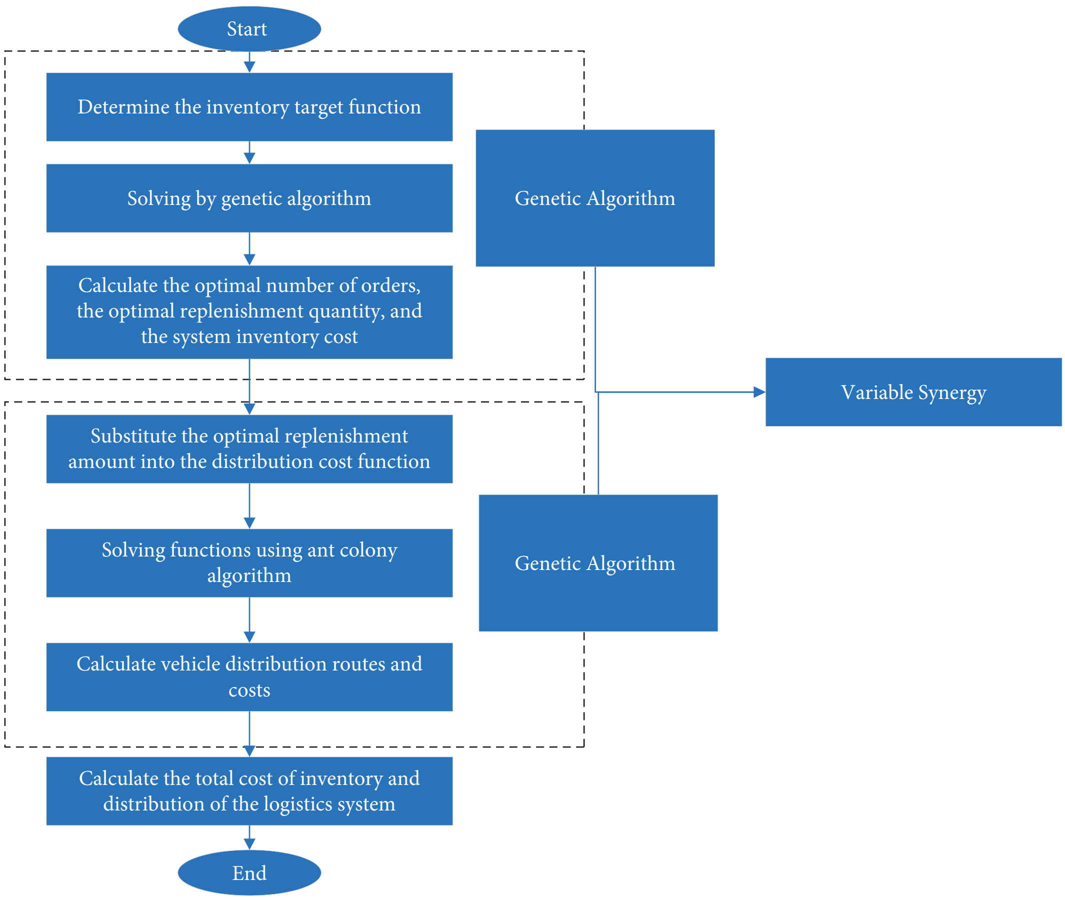

Figure 5: Collaborative optimization solution process.

$$P_{ij}^{k}(t)=\begin{cases}\dfrac{\tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t)}{\sum_{s\in j_k(i)}\tau_{is}^{\alpha}(t)\eta_{is}^{\beta}(t)}, & j\in j_k(i)\\ 0, & else,\end{cases} \tag{21}$$

where $\tau_{ij}(t)$ is the amount of pheromone secreted on path (i, j) when the ant moves from city i to city j at time t; η_{ij} is the heuristic function (visibility), which refers to the expected value of ants moving from city i to city j; α is the pheromone inspiration factor; β is the visibility importance expectation heuristic factor; and $j_k(i)$ is the set of cities that ant k untraversed, where $j_k(i)=\{1,2,\ldots,n\}$.

This paper mainly designs the algorithm of the collaborative optimization model of inventory and distribution of urban fresh agricultural products cold chain logistics. Firstly, according to the characteristics of the constructed inventory optimization model and distribution optimization model, the design idea of the algorithm of this collaborative optimization model is determined, and the solution is finally determined by using a genetic algorithm and ant colony algorithm together, and the relevant theoretical analysis of genetic algorithm and ant colony algorithm is conducted.

3. Results

The object of this case study is a large fresh product retail supermarket in Beijing, which is the first batch of fresh product supermarkets in China, and after years of development, the company operates a chain of fresh product supermarkets covering 24 provinces and cities in China. Up to now, the company has developed more than 900 supermarket chains in the country, with an operating area of more than 6 million square meters, and has been ranked among the top 100 Chinese chains and the top 100 FMCG chains many times. The company has built its own distribution center in the sales region, which is responsible for the storage, processing, and distribution of regional supermarket products.

In recent years, due to the popularity of green concepts, the development of fresh product supermarkets has reached a climax, and many retail supermarkets have begun to transform into fresh product supermarkets, which has led to the expansion of the fresh product market and increased competitiveness. In such a context, the company began to focus on the costs incurred by logistics, seeking ways to “reduce costs and increase efficiency” in the fresh product inventory and distribution chain, seeking to reduce fresh food cold chain logistics costs and improve cold chain logistics operational efficiency through advanced operational management methods and inventory management control strategies. Therefore, the thesis selects a secondary cold chain logistics network consisting of 18 fresh food supermarket chains and 3 fresh food distribution centers in Beijing to test the synergistic optimization of inventory and distribution according to the needs of the enterprise.

The case designed in this paper is 18 fresh food supermarkets with 3 distribution centers, which belong to the multidistribution center's inventory and distribution cooperative optimization problem. In the process of solving the example, this paper firstly applies the center of gravity method according to the above section to transform the multidistribution center problem into the inventory and distribution of three independent distribution centers and then selects one of the distribution center problems as an example and applies the central solution strategy, distribution optimization problem, single distribution center inventory, and distribution cooperative optimization model and genetic algorithm in the above section to solve the problem.

In order to verify the validity of the synergistic optimization model of cold chain logistics inventory and distribution of fresh agricultural products, this paper analyzes the synergistic optimization of cold chain logistics inventory and distribution of three products in an order cycle $T = 3$ days in the distribution center of this large chain fresh supermarket. The freshness decay coefficients of the three products were $\alpha_1 = 2.2$, $\alpha_2 = 2$, and $\alpha_3 = 2.1$ under the case of freshness preservation measures.

In the secondary cold chain logistics system, the distribution center is responsible for the inventory and distribution of all supermarkets' fresh products, and the instantaneous replenishment and real-time information sharing between the distribution center and supermarkets can be realized. Based on the above coordinates of each fresh food supermarket and distribution center, a plane coordinate system is established on the map.

In order to facilitate the subsequent calculation, each supermarket in the distribution center is numbered; the distribution center is numbered as 0; and supermarket 1, supermarket 2, supermarket 3, supermarket 6, supermarket 8, supermarket 13, supermarket 15, supermarket 16, supermarket 17, and supermarket 18 are numbered as 1 to 10, respectively. Meanwhile, according to the inventory and distribution cooperative optimization model for distribution path planning, the distance between fresh produce supermarkets and the distance to the distribution center are measured.

In this example, the relevant parameters of the distribution center for each product are shown in Table 1.

The relevant parameters of the supermarkets for each product are shown in Table 2.

The maximum market share of 10 supermarkets for the three products, which is the maximum market demand, A_{ij}, is shown in Table 3.

The distribution-related parameters are shown in Table 4.

Among them, this paper is a collaborative optimization model established in the case that the replenishment intervals of various products in supermarkets are different, and the replenishment intervals of the same product in each supermarket are also different. The replenishment intervals of each product are different, Resulting in a distribution path based on the solution of one product that is not suitable for the distribution path of another product, and path planning is a dynamic process. Therefore, in order to facilitate the subsequent solution of path planning, this section specifies that each supermarket replenishes only one product as an example for system inventory optimization and distribution path optimization.

In this paper, the original genetic algorithm is used to obtain the local optimal solution after 50 iterations, that is, the optimal number of replenishment and replenishment quantity for each retailer when the total inventory cost of the distribution center and retailer of the fresh supermarket cold chain logistics secondary system is minimal. The optimal solution is the lowest point of the iterations.

According to the design of the genetic algorithm and the ant colony algorithm, the distribution strategy and distribution path of the distribution center are calculated. (1) The calculation results of the genetic algorithm are based on the inventory and distribution optimization model of fresh agricultural products cold chain logistics, and the inventory optimization solution of the calculation case is carried out using the genetic algorithm to derive the minimum inventory cost of the secondary logistics system of this fresh supermarket chain within one order cycle of the distribution center, including the optimal number of deliveries and the optimal distribution quantity. In the process of designing the genetic algorithm, the relevant parameters are set. The specific values are as follows: pop size of 100, cross possibility of 0.85, mutation possibility of 0.015, and max generation of 50 times.

The objective function of minimizing the inventory cost of distribution centers and retailers is solved by MATLAB genetic algorithm, and the local optimal solution is generated after 100 iterations of operation, and the total inventory cost of distribution centers and retailers in the example tends to be an optimal solution. The optimal replenishment strategy for each retailer within 3 days of an order cycle of the distribution center is shown in Table 5.

The costs associated with the distribution centers of the fresh product supermarket chain and the 10 supermarkets during the ordering interval of the distribution centers include inventory holding costs, freshness costs, damage costs, purchasing costs, and additional costs. Based on the actual research data, the total costs associated with the distribution centers were 127,343.2 RMB, and the total costs associated with the supermarkets were 8945.39 RMB.

Based on the above genetic algorithm solution, the distribution center delivers to 10 fresh food supermarkets within 3 days of the ordering cycle, and the replenishment cycle is calculated based on the number of deliveries to each supermarket. It can be concluded that the replenishment cycle of each supermarket has decimal places, which is not conducive to calculation, so the time is converted into hours

Table 1: The relevant parameters of the distribution center for each product.

Product	Initial freshness	Preservation cost	Cost factor	Fixed cost	Sourcing cost	Inventory cost	Freight costs
1	0.93	0.4	9.5		6	0.3	5
2	0.96	0.38	10	500	9	0.35	7
3	0.95	0.42	9		8	0.4	6

Table 2: The relevant parameters of the supermarkets for each product.

Product	Initial freshness	Preservation cost	Cost factor	Price flexibility	Selling price	Inventory cost	Freight costs
1	0.92	0.6	4.0	1.1	18	0.6	5
2	0.93	0.5	4.5	1.15	22	0.8	7
3	0.93	0.45	3.8	1.2	20	0.75	6

Table 3: The maximum market demand.

Maximum demand	A_{1j}	A_{2j}	A_{3j}	A_{4j}	A_{5j}	A_{6j}	A_{7j}	A_{8j}	A_{9j}	A_{10j}
1	479	486	488	479	481	490	476	492	482	479
2	491	482	472	482	488	473	489	490	489	485
3	487	492	486	483	477	487	493	476	495	492

Table 4: The distribution-related parameters.

Parameter	Packaging and handling costs	Vehicle start-up costs	Unit shipping costs	Driver's labor cost	Vehicle average speed	Max. loading
Symbol	C_0	S	S_1	S_2	v	G
Unit	RMB/kg	RMB/time	RMB/km	RMB/time	km/h	kg
Value	0.4	40	3	100	50	1,000

Table 5: The optimal replenishment strategy for each retailer.

Market	Replenishment product	Replenishment times	Replenishment volume	Actual demand	Spoiled goods
1	1	7	158.98	155.58	3.4
2	2	7	144.82	142.47	2.35
3	1	6	188.22	183.59	4.63
6	3	7	157.57	154.63	2.94
8	2	6	170.82	167.62	3.2
13	3	7	159.22	156.25	2.97
15	3	6	187.31	183.28	4.03
16	1	4	276.98	267.19	9.79
17	2	6	171.30	168.09	3.21
18	2	4	248.71	241.94	6.77

for calculation, the time unit of the distribution service is hours, and the total time of replenishment is 72 hours.

Based on the optimal number of replenishments and the optimal replenishment quantity of each fresh food supermarket calculated by the genetic algorithm and the operating time of each replenishment of the supermarket, the optimal distribution path of the distribution center was solved by using the ant colony algorithm. According to the results of the algorithm, the distribution center makes 17 deliveries for each supermarket within 3 days of an order cycle; and the total vehicle travels 767.2 km; and the total cost of delivery is 4,695.1 RMB. In this paper, we firstly use a genetic algorithm to solve the minimum total inventory cost of distribution centers and fresh food supermarkets and calculate the optimal replenishment quantity and replenishment times for each fresh food supermarket, based on which we use an ant colony algorithm to solve the distribution path with the minimum distribution cost. Therefore, the total cost of the cold chain secondary logistics system of the fresh supermarket chain within one order cycle 3 of the distribution center is 140,983.69 RMB.

In order to further elaborate on the rationality and feasibility of the urban fresh product cold chain logistics inventory and distribution synergy optimization model, this section introduces the data related to inventory and distribution in the actual operation of the fresh product supermarket chain for comparison, which mainly includes the order quantity of the distribution center, the replenishment quantity and the replenishment times of each supermarket.

The distribution center inventory costs, supermarket inventory costs, distribution costs, and total system costs for the actual operation of this fresh product supermarket with separate decisions are compared to the costs associated with the inventory and distribution synergy strategy derived in this paper, as shown in Figure 6.

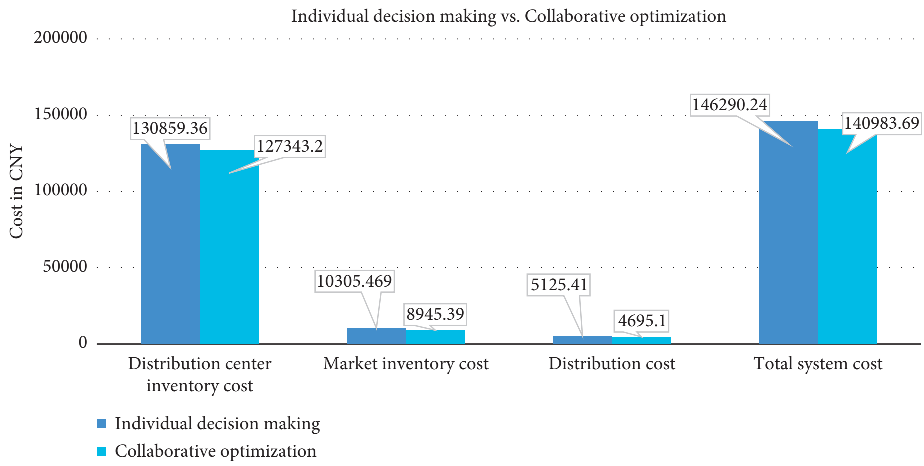

Figure 6: Cost comparison of stand-alone decision-making and collaborative optimization.

Compared with the separate decision, the total cost of the system solution of inventory and distribution co-optimization in this paper is reduced by 5,306.55 RMB. This is because the synergistic optimization model is based on the freshness function and the deterioration rate function of fresh agricultural products, which largely ensures the freshness of fresh products and reduces the deterioration loss of products, thus reducing the cost of goods loss in the distribution center. In addition, the distribution cost is reduced by 430.31 RMB, which is mainly due to the fact that the distribution model is solved in the delivery path with the lowest delivery cost, which reduces the cost of distribution to a certain extent. After solving the collaborative optimization model, the supermarket inventory cost is reduced by 1,360.079. This is due to the fact that the collaborative optimization model in this paper is based on the fact that customer demand is determined by the freshness of fresh products and the sales price. The model ensures that the sales volume of the supermarket increases per unit replenishment cycle and the time that the products occupy the inventory is reduced by minimizing the decay rate of freshness, thus reducing fresh product supermarkets' inventory costs.

4. Conclusion and Discussion

This paper takes urban fresh agricultural products cold chain logistics as the research object; analyzes the relationship among freshness cost input, freshness, and deterioration rate; establishes a collaborative optimization model of urban fresh agricultural products cold chain logistics inventory and distribution based on a single distribution center under the condition that the customer market demand is influenced by both freshness and sales price of fresh agricultural products; and proposes a partitioned solution strategy for the multidistribution center problem. Among them, the main work of the thesis is as follows. (1) The thesis takes the secondary system composed of urban fresh agricultural products cold chain logistics distribution center and retailer as the research object; analyzes the relationship between fresh agricultural products freshness function, deterioration rate function, freshness cost input, and so on; also analyzes the relationship between customer demand and product freshness and sales price; and establishes the urban fresh agricultural products cold chain logistics inventory and distribution collaborative optimization based on single distribution center. The model of optimization is established. (2) The thesis analyzes the structure of the cold chain logistics secondary network with multiple distribution centers for fresh agricultural products, proposes a strategy of partitioning solution, uses the center of gravity partitioning method to partition each retailer, converts the multiple distribution center problem into a single distribution center problem, and finally solves it through the single distribution center inventory and distribution cooperative optimization model. (3) The thesis realizes the combination of a genetic algorithm and ant colony algorithm to solve the problem. Firstly, the genetic algorithm is used to solve the optimal distribution volume and number of deliveries for each retailer by distribution center under the condition that the total sum of inventory cost of fresh product distribution center and retailer inventory cost is minimized. (4) The thesis verifies the feasibility of the collaborative optimization model of inventory and distribution of urban fresh agricultural products cold chain logistics by designing practical arithmetic cases, using MATLAB genetic algorithm and ant colony algorithm, and at the end, the minimum cost, optimal order quantity, optimal distribution quantity, and distribution route are derived. (5) In the modeling process, the relationship between freshness input cost and freshness and deterioration rate is considered more comprehensively, and the effective customer demand is combined with freshness and sales price to design the actual customer demand function. At the same time, the paper comprehensively considers the actual influencing factors, such as the limitation of each retailer on the delivery time and the maximum load capacity of the vehicle.

Based on the above analysis, the following conclusions can be drawn: (1) The cooperative optimization model of inventory and distribution of urban fresh agricultural products cold chain logistics based on the freshness and customer demand influenced by both freshness and sales price is practical and feasible, and the model solution can realize the cooperative optimization of inventory and distribution of urban fresh agricultural products cold chain logistics secondary system. (2) The algorithm designed in this paper is feasible, and the genetic algorithm and ant colony algorithm of the collaborative optimization model designed in this paper can solve the optimal solution of the secondary system of urban fresh product cold chain logistics through the calculation example. (3) The strategy of the center of gravity partitioning designed in this paper can realize the solution of the problem of multiple distribution centers corresponding to multiple retailers and convert the complex multidistribution center problem into a single distribution center problem to be carried out; therefore, the solution strategy has certain practicality.

The problem of collaborative optimization of inventory and distribution of urban fresh agricultural products cold chain logistics involves complex and uncertain constraints and influencing factors in practice, which needs continuous improvement in practice. Based on the previous theories, this paper further investigates such problems and establishes an inventory-distribution collaborative optimization model for urban fresh product cold chain logistics, considering freshness cost input, freshness, deterioration rate, and customer demand, and designs an algorithm that conforms to the model, but many practical influencing factors are ignored in the modeling and solving process, so there are more problems that need further research, such as: (1) this paper does not study the freshness of fresh agricultural products in the inventory and distribution of loading and unloading, handling, and other aspects of the irreversible damage to product quality caused by irregularities in the operation, but in the actual distribution process, the damage caused by a handling of the product exists, so this factor needs to be taken into account in the subsequent research. (2) The paper only considers the case that the distribution center delivers only one product for each retailer in the solution of the calculation, but in practice, there are multiple products replenished by each retailer, and the replenishment cycle of each product is different for each retailer, so this situation needs to be improved in the subsequent research. (3) The model in this paper is a system optimization model constructed based on the fact that customer demand is influenced by both product sales price and freshness, but in the actual operation of fresh product supermarkets, customer demand is stochastic, so the theory related to stochastic demand should be improved in future research on inventory and distribution optimization.

Data Availability

The data set can be obtained from the author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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