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FRESHNESS-DRIVEN VEHICLE ROUTING PROBLEM: MODELING AND APPLICATION TO THE FRESH AGRICULTURAL PRODUCT PICK-STORAGE-TRANSPORTATION

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Abstract. The fresh agricultural product (FAP) has highly perishable, hard to storage, and huge cost during the picking, storage, and transportation stage. In this paper, we aim to develop a multi-objective optimization model to minimize the total cost of collecting the FAP, where from the acquisition points aside the planting areas to the collection center, and the cost of transferring them to the processing factories (demand points) as well as to minimize the freshness decay during these processes. A epsilon constraint algorithm is used to convert the objective, freshness decay into constraints, and the model is transformed into a single-objective optimization model. According to the characteristics of the model, a hybrid algorithm based on genetic algorithm is developed. In order to verify the effectiveness of the model and algorithm, an example of yellow peach in Yanling, Hunan, China is constructed. And a comparison algorithm, simulated annealing algorithm, is presented. The results show that the effectiveness and efficiency of the hybrid algorithm based on genetic algorithm is better than that of simulated annealing algorithm. The insights of the sensitivity analysis indicate that the model and algorithm presented in this paper can be extended to other FAPs.

1. Introduction.

With the continuous promotion of rural revitalization, fresh agricultural product (FAP) as such yellow peach, navel orange, or regional characteristic products (eg. Yangcheng Lake hairy crab) have become an important channel for farmers to increase their income [13]. However, FAP have strong seasonality, poor preservability, short warranty cycle and high warranty cost. Therefore,

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quickly delivered FAP to processing factory and processed into various forms of agricultural and sideline products can be kept longer, not only meet users' demand for the FAP in the quarter, but also satisfy people's increasingly diverse material needs. It is an important way to stabilize the price of fresh agricultural products, improve the income of local residents and achieve the balance between supply and demand of FAP [26, 41, 42].

The development of cold chain technology improves the quality of FAP, namely freshness, to a certain extent, but at the same time brings an increase in logistics costs [7]. Therefore, establishing an efficient cold chain logistics network for FAP processing to balance the freshness and logistics cost is the key problem that processing enterprises and local governments need to solve urgently. This is also an important way to increase local farmers' income, reduce logistics costs of FAP, improve the freshness of FAP, increase social benefits and promote the development of rural revitalization [25, 10].

There are differences between the cold chain logistics network of FAP processing and general products production and processing: (1) FAP are perishable, so it is necessary to consider the control of temperature and humidity during the pick-storage-transportation stage; (2) FAP have strong seasonality. On the one hand, the picking time of FAP is relatively fixed and short (eg., the picking time for yellow peach is July and August). On the other hand, the producer of FAP is relatively concentrated. Therefore, the output may exceed the capacity of collection vehicles, so it is necessary to split the products and use multiple vehicles to collect. (3) The processing cold chain logistics network has multiple objectives. It needs to consider both the cost of the cold chain logistics network and the constraints on the freshness requirements of FAP, because the freshness will decay with the process of collection, storage and transportation [15, 29, 28].

Therefore, this paper proposes a spilit pick-up and freshness constrained integrated optimization model for FAP, which firstly constructs a multi-objective optimization problem to minimize the cost of pick-storage-transportation and freshness decay. Then, a epsilon constraint algorithm [17] is used to transform the objective of minimizing freshness decay into a constraint, so as to transform the multi-objective optimization problem into a single-objective optimization problem for solving. And analyzing the separable demand in the FAP collection link to carry out vehicle routing. Finally, considering the demand of FAP collection can be split, then a hybrid algorithm based on genetic algorithm (GA) is used to solve the vehicle routing problem. And we illustrates the effectiveness of the model by taking the pick-storage-transportation of yellow peach in Yanling County, Hunan Province, China as an example.

The contributions of this paper mainly include: (1) Our optimization model is a three-layer integrated optimization model including pick, storage and transportation, which can better improve the performance of logistics system; (2) Considering split pickup to improve vehicle utilization; (3) A multi-objective optimization model is established to minimize cost and freshness decay, and two algorithms, Epsilon+GA and Epsilon+SA algorithm, are designed to solve the model, and the results are compared and analyzed; (4) The model and algorithm are extensively verified by real cases, which proves that it has the value of popularization and application.

The remainder of the paper is structured as follows. In Section 2, We introduce the related work of FAP vehicle routing problem. The problem description and its mathematical model are presented in Section 3. The algorithm is described in Section 4. Case study and computational experiments are conducted in Section 5. Finally, the Conclusions section resumes the main findings of this work and gives some hints for future research.

2. **Literature review.**

2.1. **Logistics for fresh agricultural products.**

2.1.1. ***FAP logistics considering multi-objective.*** In the actual decision-making process of FAP logistics, many objectives are usually considered. Generally, multiple objectives such as operating cost, carbon emissions and customer satisfaction are considered comprehensively to build the model. A problem of multi-objective cargo balancing with time was solved using the window and time dependence of gradient evolution (GE) algorithm in [16]. Utama et al. [32] studied the vehicle routing problem of perishable goods (VRPfPG) and divided the optimization method into single-objective optimization problem and multi-objective optimization problem. It is proved that metaheuristic algorithm is an optimization method to solve single objective and multi objective problems. Zhu et al.[43] proposed a new vehicle routing problem (VRP), which reduced the cost of goods damage in the distribution process by relying on the investment of freshness maintenance cost. Based on all the relevant costs, a mathematical model is established to minimize the total distribution costs, and a hybrid ant colony algorithm is designed to solve the problem. Wang et al.[34] established a customer satisfaction evaluation model based on fuzzy logic. And a mathematical model was built for the intelligent distribution of smart city, which objectives are to minimize distribution cost and maximize customer satisfaction. To this end, they proposed an improved quantum behavior particle swarm optimization (IQPSO) algorithm to solve the model.

2.1.2. ***Integrated optimization for FAP logistics***. The general logistics links of FPA include collection, storage, transportation and sales. For logistics operation managers, we must reasonably optimize all logistics links. At present, in many literatures, the authors study one of them respectively, in which there are relatively few studies on the integrated optimization of the logistics process of fresh agricultural products. Fikry et al.[11] established an integrated optimization model based on binary integer programming for the production and transportation of sugar beet supply chain, with the goal of minimizing the overall operating costs of transportation and inventory of processed and unprocessed sugar beets. Nasr et al.[24] aimed at the four level multi cycle supply chain and minimized the total distribution cost, to establish a mixed integer linear programming (MILP) integrated optimization model for the location inventory routing problem of perishable products by considering the aggregation of farmers, and proposed a solution algorithm combining Lagrange relaxation method with genetic algorithm (GA). Tiwari and Sinjana.[9] proposed a new genetic algorithm to avoid revisiting in order to integrate and optimize the existing production, inventory holding and distribution, and adopted a parameterless adaptive mutation operator to find the optimal integrated inventory strategy of perishable goods in a multi-stage supply chain, and verified that their models and optimization methods gave near optimal results for different demand scenarios.

2.2. **Split pickup vehicle routing problem.** The traditional vehicle routing problems (VRP) research are mainly focused on one direction, which the maximum load capacity of vehicles can meet the needs of customers and the production of goods at the same time. However, when the actual distribution process, the maximum load of the vehicle is often greater than the customer demand or less than the production of goods. One the customer's demand is split to form a demand detachable vehicle routing problem (SDVRP), and another the collected items are split to form a goods collection detachable vehicle routing problem (SPVRP). At present, there are many studies on SDVRP, and the research on SPVRP is often integrated with SDVRP. The typical feature of SPVRP is that the maximum load capacity of the vehicle is greater than the supply capacity of the pickup point (customer), so the vehicle needs to visit multiple customers at one time. The goal of SPVRP is to improve the load rate of vehicles, reduce the number of vehicles used and save the driving path, ultimately save transport costs and improve logistics efficiency.

Wang et al.[36] considered the split vehicle routing problem (VRPSPDP) to meet the restrictions on the access time and vehicle capacity of each customer. They proposed a two-stage heuristic method combining initial heuristic algorithm and hybrid heuristic algorithm to study VRPSPDP problem. Lee et al.[18] studied a separable multi vehicle routing problem (mVRPSP) and developed a new model for mvrpsp, namely deterministic dynamic program (DP). The DP formula is based on the shortest path search algorithm, so that a new accurate algorithm to solve mVRPSP is proposed to drop total transportation cost of the fleet. Casazza et al.[6] studied the split vehicle routing problem for the collection and delivery of a single commodity. They proposed a new formula, in which paths are decomposed into simple substructure sequences called clusters, to reduce the combinatorial overturning of feasible solutions. They also introduced effective inequalities, designed a branching and pricing algorithm, used special pricing routines and branching strategies, and embedded rounding heuristics to speed up pruning. Wang et al.[35] studied the multi base pick-up and delivery vehicle routing problem, under the constraints of customer demand segmentation strategy and time window, and proposed a three-dimensional customer clustering algorithm based on load sharing strategy, which each customer is reassigned to its beneficial service provider. A hybrid genetic algorithm with tabu search was designed to optimize the picking and distribution routes and maximize the utilization of logistics resources. It showed that the co-operation and demand segmentation strategies used in network optimization can be used to provide reference for logistics operation management, and promote a sustainable collection and receipt network. Nagy et al.[23] studied the savings that can be achieved by allowing separate delivery of goods, and delivery quantity on the basis of the number of goods, that must be delivered at the same time under the separable delivery collection vehicle routing problem model. Xu et al. [37] proposed an integer linear programming model, which based on the vehicle rescue process of people in residential areas under disaster scenarios - Multi parking lots, and shelters heterogeneous cargo collection separable vehicle routing problem (MPSHVRPSP) model. They used a tabu search (TS) algorithm with diversified strategies to solve the model. Mahjoob et al.[20] proposed a multi cycle inventory path problem with separable demand for goods collection. They reduced the system cost by realizing picking up and batch delivery at the customer node, and incorporated environmental factors into the modeling framework to reduce the adverse impact of transportation

TABLE 1. Split pickup vehicle routing problem-a literature overview:

Author	Research contents	Research objectives	Algorithm type
Wang Y, Ma X, Lao Y, et al.(2014)	The vehicle routing problem with split deliveries and pickups	Release restrictions on customer access time and vehicle capacity	Initial heuristic algorithm and hybrid heuristic algorithm
Lee C G, Epelman M A,White III C C, et al.(2006)	A multiple -vehicle routing problem with split pick-ups	Reduce the total transpor -tation cost of the fleet	DP formula
Casazza M, Ceselli A, Calvo R W. (2021)	A single commodity pickup and delivery vehicle routing problem	Maximize modeling flexibility and computational efficiency	Branch and price algorithm, rounding heuristic algorithm
Wang Y, Li Q, Guan X, et al.(2021)	The multi-depot pickup and delivery logistics networks	Improve the efficiency of logistics transportation	3D customer clustering algorithm and hybrid genetic algorithm
Nagy G, Wassan N A, Speranza M G, et al.(2015)	The vehicle routing problem with divisible deliveries and pickups	Save individual delivery pickup and delivery quantity	Hybrid heuristic algorithm
Xu L, Wang Z, Chen X, et al.(2022)	Heterogeneous vehicle routing problem with split pickup model	Achieve efficient evacuation	TS algorithm
Mahjoob M, Fazeli S S, Tavassoli L S, et al.(2021)	A multi-period inventory routing problem with pickup and split delivery	Realize picking and batch delivery to reduce system cost	Transcendental method

operations. This study provides a set of Pareto solutions for decision makers to choose the best solution according to their preferences.

TABLE 1 summarizes the literature on the split delivery and pickup vehicle routing problem, as described in this section.

2.3. **Quality decay modeling for FAP.** People's consumption tendency of FAP is more concentrated on the quality of FAP, and freshness is one of the most critical factors affecting the quality of FAP. However, there must be natural decay of quality and the decay of external factors in the process of harvesting and selling FAP. Next, We will classify the quality decay modeling of FAP.

TABLE 2. The quality decay of FAPs-a literature overview:

Author	Research contents	Research conclusion	Time window	Whether external factors are considered
Soysal et al.(2018)	Quality Decay modeling of perishable products	If beyond this shelf life, it will be wasted	No	Yes
Pretorius C J, Steyn W J M.(2019)	Tomato quality decay and road conditions	It is necessary to balance transportation cost and product loss cost	No	Yes
Mishra et al.(2016)	Parameters related to the quality index of fresh agricultural products	Fresh agricultural products difficult to maintain sensory quality	No	Yes
Liu L, Wang H, Xing S.(2019)	Maturity a maturity model of soluble solids for agricultural products	Maturity models can accurately predict maturity	Yes	No
Stellingwerf H M, Groeneveld L H C, Laporte G, et al.(2021)	A time-and temperature-dependent kinetic model for a vehicle routing problem	Longer, multi-stop routes lead to greater loss of food quality	Yes	No
Çakmak B, Alayunt F, Akdeniz C, et al.(2010)	Related factors of fruit damage caused by vibration	The quality decay caused by vibration is related to the product type	No	No
de Keizer M, et al.(2017)	Integrate product quality decay and its heterogeneity into network design model	Heterogeneous product quality decay will significantly affect network design and profitability	No	No

The decay of quality is random Modeling the quality decay without considering the influence of external factors. Soysal et al.[30] proposed green Inventory Routing

Problem(IRP) for modeling the quality decay of perishable products. They set a fixed shelf life for each product, beyond which it will be wasted and cost loss will occur. Logistics operations can cause many forms of cuts and bruises on harvested FAP, which can affect their quality and appearance. Pretoria and Stein[27] monitored the transportation conditions of trucks loaded with tomatoes and created a model. They linked the damage and decay of tomatoes in the shelf life with road conditions, fruit maturity and the location in the container. Thus, logistics planners can weigh the transportation cost and the cost of product decay during transportation during route planning. Mishra et al.[22] estimated the parameters related to the quality indicators of fresh agricultural products based on their own experience, such as the appearance, wilting, browning of fresh cut lettuce, and put them into the Arrhenius equation. In their study, quality decay was modeled as a percentage of the initial quality decay.

Under the influence of external factors. In order to simulate the quality attenuation modeling, we will approximate one of the factors affecting the quality of FAP – "temperature" to ideal. Liu et al.[19] added strict time requirements into the distribution plan of FAP. They established a soluble solid maturity model of agricultural products by restricting the concentration, temperature and storage time of ethephon. And based on ant colony algorithm, a distribution model of agricultural products was built to ensure that agricultural products arrive on time. A time - and temperature dependent kinetic model for the vehicle routing problem was proposed by Stellingwerf et.al[31]. The extension of vehicle distribution problem proposed by them can quantify the quality decay on the route.And the results showed that the longer and multi station route would have a negative impact on food quality, especially for the products that arrived late in the route. In fact, vibration usually caused some quality decay to perishable fruits in transportation. We know that fruit damage due to vibration is related to vehicle transport characteristics, packaging and road conditions. And studies have shown that cardboard boxes are not suitable for transporting fresh figs under all road conditions [5]. de Keizer M et al.[8] proposed a new mixed integer linear programming formula, and considered the heterogeneity of perishable product quality decay. The formula can locate inventory and allocation process under quality constraints to maximize profits. Therefore, heterogeneous product quality decay should be considered in network design, because it will significantly affect network design and its profitability.

TABLE 2 summarizes the literature on modeling the quality decay of fresh agricultural products, as described in this section.

3. **Problem description and modeling.**

3.1. **Problem description.**

As shown in Fig. 1, let $G = (V, A)$ be a directed graph, which represents the vehicle network structurefor FAP pick-up and delivery. The node set is $V = I \cup J \cup K$, where I is the set of FAP collection center , and J is the set of FAP planting regions. There is path connection between planting regionss, and K is the set of FAP factory. The number and location of planting regions and factory have been determined, and there is a candidate set of construction points of the collection center. The decision variable x_i determines whether to build a collection center at the candidate site. The set of edges are denoted as $A = \{(i,j) : i,j \in V, i \neq j\}$. Suppose the annual picking time of FAP as T, and set that FAP is collected from each planting regions to each collection center for storage every day. Since the production capacity may be less than the vehicle

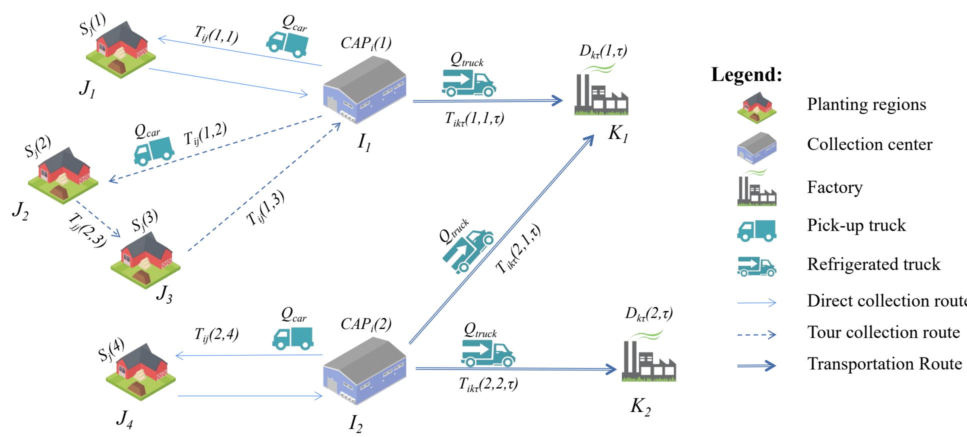

FIGURE 1. Schematic diagram of FAP pick-storage-transportation

capacity, the vehicle cannot be fully loaded, resulting in waste of vehicle carrying capacity. Therefore, it is necessary to consider split pick-up vehicle routing problem. If FAP are transported from the collection center to the factory every δ days, and its freshness will be decayed during the transport process. Then we assume that:

(1) The distance between any two points is symmetric, that is $d_{ij} = d_{ji}$;

(2) All vehicles must depart from the collection center to the planting regions to collect FAP, after completing the collection task, they must return to the collection center;

(3) The quantity delivered to the factory K from all collection center meets the demand of K, and each transportation task from the collection center to the factory can be completed by one or more vehicles. However, it is not necessary to distribute all the inventory in the collection center for each transportation task;

(4) At most, only one of all pick-up truck is not fully loaded, and the rest are fully loaded.

The problem to be solved is how to integrate and optimize the pick, storage and transportation of FAP within time quantum T, so as to minimize the logistics cost and freshness decay.

3.2. **Notations.** The nations used in this paper are shown in Table 3.

Table 3: The set, variables and paremeter used in the model

Notations	Definition
set	
I	Set of townships, $i = \{1, 2, \cdots, I\}$.
J	Set of villages, $j = \{1, 2, \cdots, J\}$.
K	The set of yellow peach factory, $k = \{1, 2, \cdots, K\}$.
V	A set of villages and collection center, $V = \{I, J\}$.
C	Set of pick-up truck, $c \in C$.
U	Set of refrigerated truck, $u \in U$.

Notations	Definition
Decision variables	
$x_i = \{0,1\}$	Binary variable, if $x_i = 1$, it means to build collection center, otherwise $x_i = 0$.
p_{cijt}	The quantity of FAP from point j to i in train c on day t.
$q_{uik\tau}$	The quantity of FAP from i to k in τth uth trip.
$y_{ijt} = \{0,1\}$	If collect FAP from collection center i to village j on day t, $y_{ijt} = 1$, otherwise $y_{ijt} = 0$.
$z_{cijt} = \{0,1\}$	If pick-up truck c goes from node i to j on day t, $z_{cijt} = 1$, otherwise $z_{cijt} = 0$;
$v_{ik\tau}$	The amount of FAP transported from i to k in the τth time.
Parameter	
P	FAP unit product market price
F_i	Construction cost of collection center i.
CAP_i	Capacity of collection center i
R_{car}	Car rental cost and drivers' salary.
O_i	Operating cost per unit product of collection center i.
Q_{car}	Capacity of pick-up truck.
Q_{truck}	Capacity of refrigerated truck.
R_{truck}	Refrigerated truck rental cost and drivers' salary.
T_{ij}	Travel time from node j to i.
δ	Delivery interval of refrigerated truck.
τ	τ th shipment.
$T_{ik\tau}$	Travel time of refrigerated truck from i to k.
$TC_{1,2}$	Cost per unit weight per unit transport time, where 1 represents pick-up truck,2 represents refrigerated truck.
S_j	Anual output of village j.
S_{jt}	Output of village j on day t.
$D_{k\tau}$	Volume of demand of factory k at τ th transportation.
$W_{i,t}$	Inventory of collection center i at day t.
TT	Total time for collection, storage and transportation

3.3. **Modeling formulation.** In this subsection, a multi-objective integrated optimization model is formulated to minimize the total cost of FAP collection, storage and transportation, and minimize the decay of freshness. They are given by

$$\Pi_1 = \min\{FC + RC + OC + RT + PC + DC + LC + LR + LS\} \tag{1}$$

subject to

$$FC = \sum_{i \in I} F_i x_i \tag{2}$$

$$OC = \sum_{i \in I} \sum_{j \in J} \sum_{t=1,2,\cdots,30} O_i S_{jt} y_{ijt} \tag{3}$$

$$PC = \sum_{t=1,2,\cdots,30} \sum_{i \in V} \sum_{j \in V, i \neq j} \sum_{c} TC_1 p_{cijt} T_{ij} z_{cijt} \tag{4}$$

$$DC = \sum_{i \in I} \sum_{k \in K} \sum_{\tau} TC_2 \times T_{ik\tau} v_{ik\tau} \tag{5}$$

$$RC = \sum_{i \in I} R_{car} \sum_{t=1,2,\cdots,30} \sum_{c} \sum_{j \in J} z_{cijt} \tag{6}$$

$$RT = \sum_{i \in I} R_{truck} \sum_{k \in K} \lceil \frac{v_{ik\tau}}{Q_{truck}} \rceil \tag{7}$$

$$LC = \sum_{\tau} \sum_{i \in I} \sum_{k \in K} PD_{k\tau}(1 - e^{-\alpha T_{ik\tau}}) \tag{8}$$

$$LR = \sum_{\tau} \sum_{i \in I} \sum_{k \in K} P(\sum_{t=(\tau-1)*\delta+1}^{\tau \times \delta} W_{i,t} - D_{k\tau})(1 - e^{-\alpha \times \delta}) \tag{9}$$

$$LS = \sum_{\tau} \sum_{i \in I} \sum_{k \in K} P(\sum_{t=(\tau-1)*\delta+1}^{\tau \times \delta} W_{i,t}(1 - e^{-\alpha \times (\tau \times \delta - t)})) \tag{10}$$

$$\sum_{j \in J} p_{cijt} \leq Q_{car}, \forall i \in I, \forall c \in C, t = 1, 2, \cdots, 30 \tag{11}$$

$$q_{uik\tau} \leq Q_{truck}, \forall u \in U, \forall i \in I, \forall k \in K \tag{12}$$

$$\sum_{u \in U} q_{uik\tau} = v_{ik\tau}, \forall i \in I, \forall k \in K \tag{13}$$

$$\sum_{i \in I} v_{ik\tau} = D_{k\tau}, \forall k \in K \tag{14}$$

$$W_{i,t} \leq CAP_i x_i, \forall i \in I, t = 1, 2, \cdots, 30 \tag{15}$$

$$\theta_3 \geq \sigma \geq 0 \tag{16}$$

$$\sum_{i \in V} \sum_{j \in V} z_{cijt} = \sum_{j \in V} \sum_{i \in V} z_{cjit} \geq 1 \tag{17}$$

$$\sum_{j \in J} z_{cijt} = \sum_{j \in J} z_{cjit} \leq 1, \forall i \in I, \forall c \in C, t = 1, 2, \cdots, 30 \tag{18}$$

$$\sum_{c \in C} p_{cijt} z_{cijt} \leq S_{jt}, \forall i \in I, t = 1, 2, \cdots, 30 \tag{19}$$

$$\sum_{j \in J} \sum_{t=1,2,\cdots,30} S_{jt} = \sum_{k \in K} \sum_{\tau} D_{k\tau} \tag{20}$$

$$W_{i,t} = \begin{cases} W_{i,t-1} + \sum_{c\in C}\sum_{j\in J} p_{cijt} & t \neq n\delta, n \in N^+ \\ W_{i,t-1} + \sum_{c\in C}\sum_{j\in J} p_{cijt} - \sum_{k\in K}\sum_{u\in U} q_{uik\tau} & t = n\delta, n \in N^+ \end{cases} \tag{21}$$

$$x_i, y_{ijt}, z_{cijt} = \{0,1\}, \forall i \in I, \forall j \in J, \forall c \in C, t = 1,2,\cdots,30 \tag{22}$$

$$p_{cijt}, q_{uik\tau}, v_{ik\tau} \in R^+, \forall i \in I, \forall j \in J, \forall c \in C, \forall u \in U, \forall k \in K, t = 1,2,\cdots,30 \tag{23}$$

$$\Pi_2 = \min\{1-\theta_3\} \tag{24}$$

subject to

$$\theta_1 = 1 - \eta(avg\{T_{ij}\}/TT)^2 \tag{25}$$

$$\theta_2 = \theta_1 - (1-k_2e_2)\eta(\delta/TT)^2 \tag{26}$$

$$\theta_3 = \theta_2 - (1-k_3e_3)\eta(avg\{T_{ik}\}/TT)^2 \tag{27}$$

In the formulation, the objective function 1 minimizes the total cost of FAP pick, storage and transportation, and the decay of FAP freshness. Constraints 2 , 3 represent the cost of the collection center, where constraint 2 is the construction cost of the collection center and constraint 3 is the operation cost of the collection center. Constraint 4 defines the receiving cost of pick-up truck, and constraint 5 defines the transportation cost of refrigerated truck. Constraints 6, 7 state the departure cost, where constraint 6 is departur cost of pick-up truck and constraint 7 is departure cost of refrigerated truck. The constraint 8 represents delivery in transit loss cost. Constraints 9, 10 are residual damage cost and storage damage cost respectively.

Constraints 11, 12 represent the carrying capacity constraint, where 11 represents the pick-up truck capacity constraint and 12 represents the refrigerated truck capacity constraint. Constraint 13 is the sum of the τth refrigerated truck load is equal to the total amount transported to the factory, and constraint 14 is the quantity delivered to the factory K from all collection centers meets the demand of K. Constraint 15 and 16 respectively indicates the collection center inventory constraints and the freshness threshold constraint. Constraint 17 means that each village can be served by at least one goods pick-up truck, and the vehicles in and out of the village are balanced. Constraint 18 emphasizes that the pick-up truck needs to return to the collection center, and the number of vehicles is kept. Constraint 19 ensures that the quantity of goods collected by a pick-up truck in Village j does not exceed the supply quantity of the village. Constraint 20 is the expression for the total supply quantity is equal to the total order quantity in the whole process. Constraint 21 emphasizes this time is within the shipment period and this time is within the non-shipment period. Constraint 22 indicates decision variables. Constraint 23 ensures that these three numbers are positive real numbers.

The objective function 24 indicates the decay of FAP freshness. Constraints 25 ,26 and 27 represent the amount of freshness decay, where constraint 27 indicates the freshness after collection, storage and transportation.

4. **Algorithm design.** It is a widely accepted strategy to transform multi-objective function into single objective function and then adopt single objective optimization method to solve multi-objective optimization problem [40, 14]. To this end, we use Epsilon constraint algorithm to transform the objective function Π_2 into constraints, so as to transform the multi-objective optimization problem into a single objective problem. The methods to solve the optimal solution of the objective function Π_1 mainly include accuracy solution and heuristic solution However, when the problem scale is large, the optimal solution cannot be obtained in effective time by

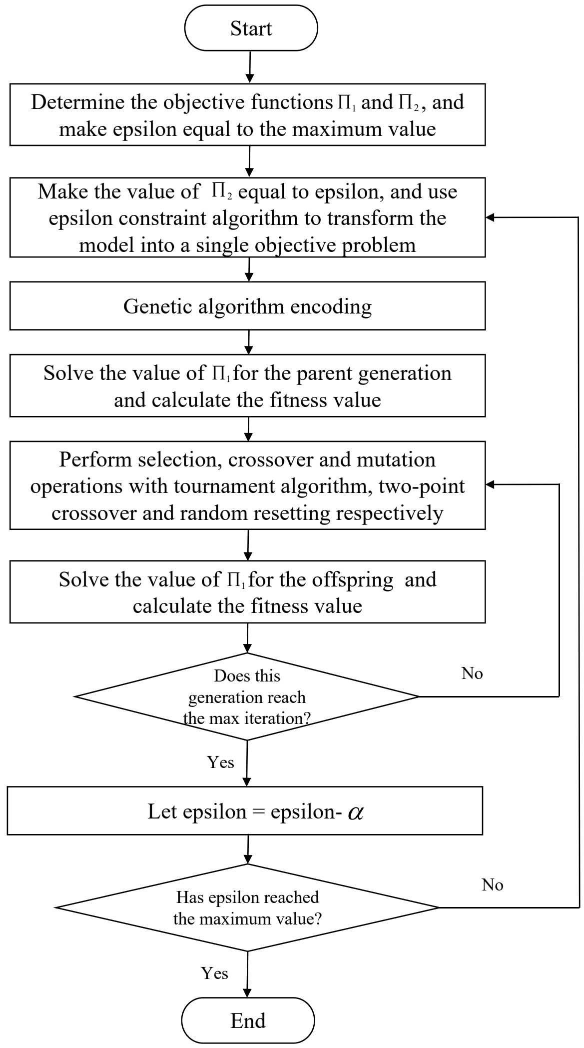

FIGURE 2. Process of EPGA

using accurate algorithm. In this case, heuristic algorithm is usually used to get the approximate optimal solution [1, 4]. In this paper, we use genetic algorithm to solve Π_1. Therefore, the design idea of the model solving algorithm we proposed combines epsilon constraint and GA, named EPGA. The detailed process is shown in Fig. 2. In addition, as a control group, we also put forward a solution that integrates Epsilon constraint and SA algorithm under the same conditions, named EPSA.

4.1. **Epsilon constraint algorithm design.** In order to accurately solve the above multi-objective optimization problem, that is, to obtain the optimal Pareto Front [33]. We use epsilon constraint algorithm for multi-objective optimization. Epsilon constraint algorithm is an accurate algorithm commonly used to solve multi-objective [39, 38] The idea is to construct and solve a series of epsilon constraint

problems by transforming one of the objectives into a constraint, and constantly change the epsilon value until the final solution of the problem is obtained [3]. For convenience of description, we make the following definitions as required:
Definition 1. Set the Ideal Point as $\Pi^{IP} = (\Pi_1^{IP}, \Pi_2^{IP})$, where Π_1^{IP} represents the optimal solution of objective function 1, i.e. $\Pi_1^{IP} = \min\{\Pi_1\}$, and Π_2^{IP} represents the optimal solution of objective function 2, i.e. $\Pi_2^{IP} = \min\{\Pi_2\}$.
Definition 2. Set the Nadir Point as $\Pi^{NP} = (\Pi_1^{NP}, \Pi_2^{NP})$, where Π_1^{NP} represents the extreme value of objective function 1 when objective function 2 takes the optimal solution, i.e. $\Pi_1^{NP} = \min\left\{\Pi_1 \mid \Pi_2 = \Pi_2^{IP}\right\}$. Similarly, Π_2^{NP} represents the extreme value of objective function 2 when objective function 1 takes the optimal solution, i.e. $\Pi_2^{NP} = \min\left\{\Pi_2 \mid \Pi_1 = \Pi_1^{IP}\right\}$.
Definition 3. Suppose the Extreme Point is the mutually dominant Pareto front on the same Pareto frontier, i.e $\Pi^{RP} = \left\{\left(\Pi_1^{IP}, \Pi_2^{NP}\right), \left(\Pi_1^{NP}, \Pi_2^{IP}\right)\right\}$.

By introducing Epsilon constraint, the multi-objective optimization problem is transformed into a single objective problem. In the multi-objective model established in this paper, both objectives are minimized. Thus, we can know that the ideal point is (0, 0), the single pole is $(\min\{\Pi_1 \mid \Pi_2 = 0\},\ \min\{\Pi_2 \mid \Pi_1 = 0\})$, and the limit point is $(0, \min\{\Pi_2 \mid \Pi_1 = 0\})$ and $\left(\min\{\Pi_1 \mid \Pi_2 = 0\}, 0\right)$. Therefore, we can set the initial value of the Epsilon constraint value as a large number Key, and reduce it according to a certain step α, it ends when the objective function value cannot be changed. The specific steps are shown in Algorithm 1.

Algorithm 1 Epsilon constraint algorithm

1: Calculate ideal point $\Pi^{IP} = \left(\Pi_1^{IP}, \Pi_2^{IP}\right)$ and nadir point $\Pi^{NP} = \left(\Pi_1^{NP}, \Pi_2^{NP}\right)$
2: Set $\Pi' = \left(\Pi_1^{IP}, \Pi_2^{NP}\right)$ and make $\epsilon = key$
3: **if** if $\Pi_2^{NP} \leq \epsilon$ **then**
4: Solve the ϵ constraint problem, where ϵ constraint is $\Pi_2 \leq \epsilon$ and the optimized single objective is $\min\{\Pi_1\}$, and add the optimal solution (Π_1^*, Π_2^*) to set Π', where $\Pi_2^* = \epsilon$
5: Make $\epsilon = \epsilon - \alpha$, and repeat step 3,4,5
6: **end if**
7: By removing the dominant points from set Π', Pareto frontier Π can be obtained.

4.2. **Genetic algorithm design.** The methods to solve the optimal solution of objective function Π_1 mainly include accuracy solution and heuristic solution. However, when the scale of the problem is large, the optimal solution can not be obtained in the effective time by using the accurate algorithm. At this time, heuristic algorithm is usually used to obtain the approximate optimal solution. So we use genetic algorithm and simulated annealing to solve the problem. This section mainly describes the solution process of genetic algorithm.

Genetic algorithm is a kind of heuristic algorithm to search the optimized point. The initializing and iterating method would impact on the solving process [21, 12]. In our model, selection and mutation are modified for better convergence. Besides, all planting regions are only served by single collection center and every town construct at most one station.

4.2.1. ***Encoding***. The chromosome is consisted of 3 segments, the lower limit of inventory in collection center, flags deciding whether to build collection center in corresponding town and all station id of each planting regions. Thus, length of the chromosome should be $1 + n + m$, where n is the number of town m is the number of planting regions. When encoding, the id of collection center serving for each planting regions would be sorted by planting regions id in ascending order and concatenated as a part of chromosome, as well as the station flags. The lower limit of collection center inventory is stored as integer in chromosome, which is 10000 time of the real lower limit. It is worth noting that we use integers for all genes to help write code. Therefore, the upper limit of the chromosome library is magnified 10000 times during storage, and then saved by reshaping. Then when we read the gene, we divide it by 10000. For example, there are 4 town identified as ♯1, ♯2, ♯3, ♯4 separately, serving for 8 planting regions, the first town will not build collection center and lower limit of station inventory is 1.25 ton. One possible chromosome encoding could be [12500, 0, 1, 1, 1, 3, 1, 2 3, 4, 3, 2, 3].

Before decoding, since not all town has an available collection center, it is necessary to check whether collection center for each planting region defined in chromosome is enabled in second segment. If not, those planting regions will be re-assigned to the nearest available collection center for decoding while the chromosome will not be modified. In addition, although the possibility is quiet low, there still would be a possible situation that all station decision flags are 0 causing no collection center is established. To avoid those meaningless individuals, we inverse to opposite case and treat them as all 1. If the second segment in chromosomes is all 0, the collection center would be constructed in every town when decoding, meanwhile, like verification of third segment, the chromosome will remain unchanged.

4.2.2. ***Decoding***. The decoding part is consisted of three stages, collecting, delivering and storage. In the first stage, since all planting regions are served by single collection center, there would be two situations to be concerned: direct collecting and touring collecting. Generally, the first situation would contain even routes on the same road with inverse direction, and the collection center would consistently send pick-up trucks to the correspondingly planting regions until remaining FAP is less than the capacity of the truck. For the second situation, after all direct pick-up trucks were sent, FAP in each planting region cannot satisfy the full transportation capacity, which means single truck could tour different planting regions to collect FAP for higher efficiency. In our model, the touring pick-up truck would route to each planting region served by the same collection center in ascending order of planting region id and collect FAP as much as possible. Once fully loading, touring trucks get back to the departure station. Then, another touring collecting would be started from the planting region with minimum id and available cargo until all peach in planting region are collected.

In the second stage, the schedule of refrigerated trucks to send FAP are arranged by the delivering interval δ and distance. To be specific, all time on the route from every town to every factory are organized in a two-dimension array. For instance, there are 7 towns and 8 factories, which means this delivering duration array contains 7 rows and 8 columns in the ascending order of station id and factory id. Each element in array represents the time for refrigerated trucks to complete the route between correspondingly collection center and factory and the path with minimum would be chosen preferentially. All routes are one-way trip since trucks are rent and it is not necessary to consider returning. As for the schedule, no cargo would be conveyed in the first day unless $\delta = 1$, meaning daily delivery, while all inventory are sent to factory at last. In the rest of time, stock in station should be delivered every day and every path in the duration array be tried with following steps.

(1) If both inventory in single collection center and the demand of factory are greater than or equal to the refrigerated truck capacity, full-load transplantation will be executed until this condition is not satisfied.

(2)If inventory in single collection center is not less than the lower limit defined in chromosome and the demand of factory is not less than the inventory, the rest of FAP in collection center would be sent to corresponding factory.

In the final stage, there are two key variables to be calculated, the storage time, storage loss, and loading amount of refrigerated trucks, important for maintenance cost and overheads. After collecting stage and delivering stage if there is in such day, the remaining FAP would be considered as storing in station for 24 hours. The loading operation for delivering would lead to extra maintenance cost and overheads depending on total weight of FAP. Moreover, the daily loading amount is not infinity due to the limited workers in each station. In our case, there are 4 times cost for extra loading above 300 ton every day.

In the whole process, all tracks of each pick-up truck or refrigerated truck and the amount of FAP stored in collection center would be recorded for cost and freshness analysis. The freshness is dependent on the time which also contains pick, storage, and transportation part but the collecting time will not account for freshness decay. After cost and freshness calculation, the individual fitness value is negated total cost with freshness penalty. If final freshness is less than specified value, fitness value should be

$$\begin{cases} -C^{1+\frac{(f_{min}-f)}{4}} & f_{new} > f > \frac{f_{min}}{3} \\ -C^{2} & \frac{f_{min}}{3} > f \end{cases} \tag{28}$$

C is total cost, f is the final freshness of individual, and f_{min} is the specified minimum freshness. However, the integration module mentioned before has internally negated the return value of specified objective function achieve optimization. Thus, our final function would return the total cost with freshness penalty directly.

4.2.3. ***Selection, crossover, and mutation***. In our model, selection algorithm is tournament with size of 3. For better iteration, the best individual in top 10% of single generation would be preserved and appear in next generation without crossover and mutation to stabilize the result. 2-point crossover is adopted for generating off-spring. In mutation step, each element in chromosome might change to another legal value, however, the rate is not fixed. The fitness value of best individual in last 5 generations would be recorded to figure out the standard deviation. Once less than 1.5 millesimal of latest total cost, the probability of mutation will increase by 20%. On the contrary, if the condition is not true, probability will decrease by 20%. To avoid unpredictable error, upper and lower boundary of probability of mutation are granted, which is 20% and 2% respectively.

4.3. **Simulated annealing algorithm design.** The simulated annealing algorithm introduces the annealing idea into the field of combinatorial optimization, and which is an approximate optimal solution optimization algorithm based on Monte-Carlo [2]. There are usually two layers of cycles in the algorithm operation process, an outer cycle and an inner cycle, where the outer cycle represents a continuous drop in temperature, and the inner cycle is a different state generated at this temperature. The design steps of the simulated annealing algorithm in this paper are as follows:

Step 1: initialize the parameters required for simulated annealing, randomly generate the initial solution S, and calculate the solution of the cost function through the solution S, that is, the total cost $C(S)$ of collecting, storing and transporting FAPs this time;
Step 2:Judge whether the inner loop reaches the upper limit of the number of iterations; if not, add 1 to the number of iterations;
Step 3: Randomly generate disturbance on the old solution S to generate a new solution S_{new};
Step 4: Judge whether the constraint conditions are met; if not, return to Step 3;
Step 5: Calculate the value of cost function $C(S_{new})$;
Step 6: Calculation $C = C(S_{new}) - C(S)$;
Step 7: If $C < 0$, S is accepted S_{new} is the new current solution S, otherwise S_{new} is accepted as probability $exp(-C/T)_{new}$ current solution S;
Step 8:Execute the temperature retreat operation. When the temperature reaches the set termination temperature, the algorithm ends and the current solution S is output. If the termination condition is not met, return to Step 2.

The output of the algorithm is a route table for collecting FAP from the planting regions and a route table for transporting FAP from the collection center to the factory. The collection route table of FAP is divided into the collection route table directly from a single planting regions, and the roving collection route table from multiple planting regions. In Step 2, the routes in the direct collection route table, and the transit stations in the itinerant collection route table are randomly modified. The state acceptance function adopts Metropolis criteria, as shown in Equation 29:

$$p = \begin{cases} 1 & F(S_{new}) \leq F(S) \\ exp(\frac{F_{new} - F(s)}{T}) & F(S_{new}) > F(S) \end{cases} \tag{29}$$

The temperature $T(t)$ in the algorithm decreases in a certain way, as shown in Equation 30:

$$T(t) = \frac{T_0}{1 + \alpha t} \tag{30}$$

5. **Case study.** In this section, we take the collection, storage and transportation of yellow peach in Yanling County, Hunan Province, China as a case for analysis. We first collected the production, storage and processing data of yellow peach in this area. Then EPGA and EPSA algorithms are implemented with Python 3, where genetic algorithm in EPGA uses scikit-opt library(Link: https://github.com/guofei9987/scikit-opt). Next, we verify and test the solution effect of the algorithm. The running platform of the algorithm is pycharm 2021, and the running environment is (CPU i7, 2.6GHz, 16g Memory). Finally, we explain the managerial insights of the model.

5.1. **Data collection.** The yellow peach is a typical fresh agricultural product. A total of 7 types of data are collected in this paper, including the annual output data of yellow peach from 2014 to 2021, location data of seven main yellow peach planting towns in Yanling County, the lacation and area data of their villages, the data of Hunan fruit processing factory and their scale and location, the distance from the township center to the processing factory in Yanling County. The symbols of planting regions, collection centers and processing factorys are shown in Table 6 in the appendix.

The annual output data of yellow peach in Yanling County from 2014 to 2021 are from the official website of Yanling County Government. Polynomial regression is used to predict the yield of Yanling yellow peach in 2022. Due to the small amount of data, better prediction results can be obtained by increasing the number of features to more than 5 times. Generally, the annual picking time of yellow peach in Yanling County is from mid July to mid August, so we assume that the harvesting time of yellow peach is 30 days.

The central location data of the seven main yellow peach planting villages and towns are from Google map, which are also used as the candidate construction location of yellow peach collection center. The central location data of the villages belonging to these seven towns are from Google map and serve as the yellow peach collection point. The travel distance from township to village and from village to village is obtained by calculating its Euclidean distance.

The administrative regions area data of villages and towns in Yanling County are from the national geographic information public service platform(Link: https://aiqicha.baidu.com/). The total output of yellow peach in Yanling County in 2022 has been predicted, and the annual output of yellow peach in each village is distributed according to the proportion of the administrative area of each village. The daily output of each village is equal to its annual output divided by the picking time. The data of Hunan fruit processing plant and the scale of the corresponding fruit processing factory are from Aiqicha (Link: https://www.tianditu.gov.cn/). We divide the demand of yellow peach by the scale of each processing factory. Then, the distance between the township centers in Yanling County and the processing factory is obtained through the navigation data of Google map.

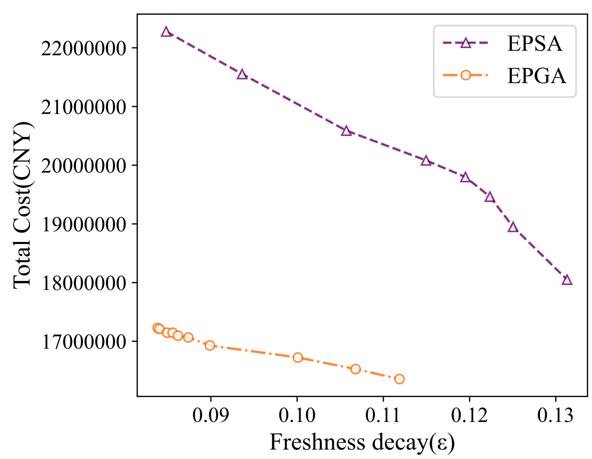

FIGURE 3. The Pareto Front of EPGA and EPSA

5.2. **Results and sensitive analysis.** In this subsection, first, we use EPGA and EPSA algorithms to solve the optimal Pareto Front solution set of the model. As shown in Figure 3, The horizontal axis represents the FAP freshness decay, that is the value of ε. The vertical axis represents the objective function, that is the value of Π_1. When the freshness decay exceeds 0.3, FAP is considered not to be available for sale. Therefore, the initial value is set to 0.15, the step size is 0.001, and the minimum value is set to 0.08. In this experiment, δ is set to 1, which means that the yellow peaches will be transported to the processing factory immediately after the yellow peaches are collected on the same day. The values of k_2 and K_3 in the freshness functions(Equation (26) and (27)) are set to 1.1, the values of e_2 and e_3 are set to 0.8384, and the value of η is set to 3. Each group of experiments was repeated 10 times, and the results were taken as the average value. All points in the graph represent the points on the optimal Pareto Front. The total cost continues to increase with the decline of freshness decay, and the growth rate is gradually increasing. The extreme point in EPGA is $(0.084, 17226613)$. Extreme point in EPSA $(0.085, 22277895)$. Under the same freshness, the cost of EPSA is at least 25% higher than that of EPGA.

According to the survey of the fruit processing factory, the fruit processing factory expects the freshness of yellow peach to be greater than 0.9. Therefore, we give a freshness decay as 0.1, and δ as 1. The iterative curve of EPGA is shown in Figure 4. It can be seen that the experimental iteration converges 20 times, and the lowest cost of solution is 16928681. Further, we get the transportation scheme in this case, as shown in Figure 5.

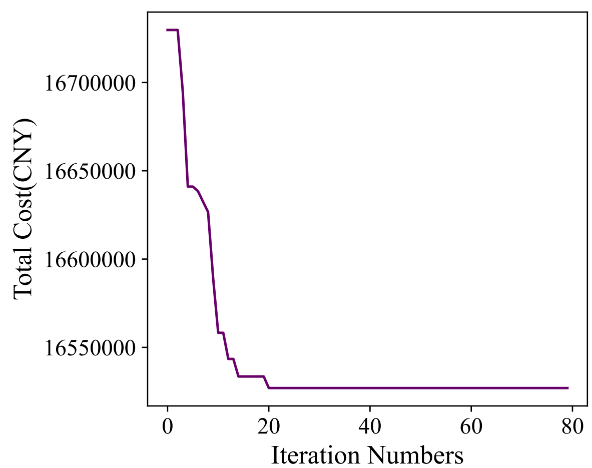

FIGURE 4. Iteration curve diagram of EPGA

Finally, we conducted sensitivity analysis on the important parameter δ, and discuss the impact of δ on the total cost and freshness. Increase the value of δ from 1 to 5, and solve the model to obtain the Pareto optimal solution, as shown in Figure 6. It can be seen from the experimental results in Figure 6. As δ is 1, the total cost is the lowest. When δ is greater than 1, the total cost increases due to the operation of the collection center and the increase of cargo damage costs. With the increase of δ, the freshness decay also increases. This is because the increase of δ means that the storage time of yellow peach in the collection center will increase. At the same time, the storage time is longer than the collection and transportation time in most cases, and the fresh-keeping condition of the collection center is worse than that of the transportation vehicles, which eventually leads to a significant decline in freshness. We also give the construction of the collection center and the planting regions they serve under different δ value, as shown in Table 5. When δ is 1, it is optimal to build two collection center. When δ is 2, it is the best to build three collection center. When δ is greater than 2, it is optimal for all candidate points (a

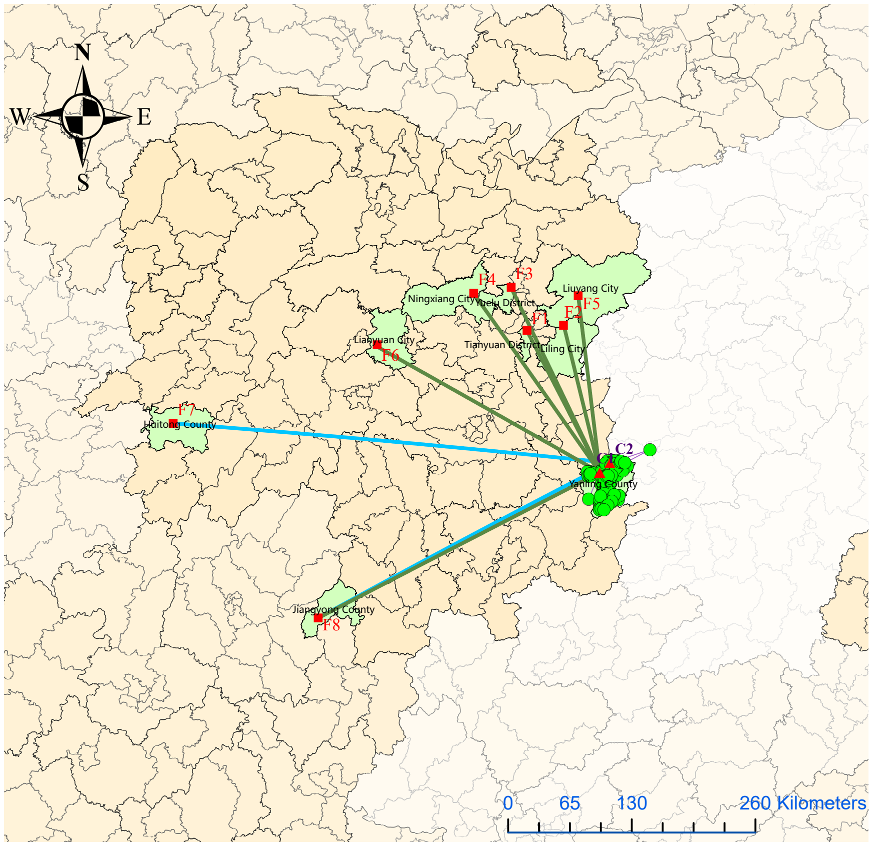

FIGURE 5. Example diagram of transportation plan

total of 7) to establish collection center.The settings of the parameters involved in the above experiments are shown in Table 4.

Table 4: Values of parameters used in the model

Parameter	**Value**
P	11000 CNY/ton
Fi	100000 CNY
CAP_i	10000 ton
R_{car}	200 CNY
O_i	100 CNY
Q_{car}	5 ton
Q_{truck}	12 ton
R_{truck}	1000 CNY
$TC_{1,2}$	100/200 CNY

TABLE 5. The construction of collection center and the distribution of planting regions they serve under different δ

δ	Collection center	Planting regions
$\delta = 1$	C1	P1,P2,P3,P4,P6,P8,P10,P11,P12,P13,P14,P15, P16,P17,P18,P19,P23,P24,P27,P28,P29,P40,P41, P42,P48,P49,P50,P51,P52,P53,P54,P55,P56,P58, P60,P61,P62,P63,P64,P65,P66,P68,P69,P70,P71, P72,P73,P74,P75,P76,P77,P78,P79,P80,P81,P82, P83,P85,P86,P88
	C2	P2,P5,P7,P9,P20,P21,P22,P25,P26,P30,P31,P32, P33,P34,P35,P36,P37,P38,P39,P43,P44,P45,P46, P47,P57,P59,P67,P84,P87
$\delta = 2$	C1	P1,P2,P3,P4,P5,P7,P8,P9,P10,P11,P12,P13,P14, P15,P16,P17,P19,P20,P23,P24,P25,P26,P27,P28, P29,P30,P31,P32,P36,P37,P38,P43,P46,P47,P60
	C5	P5,P21,P22,P33,P34,P35,P39,P40,P41,P42,P44, P45,P48,P49,P50,P51,P56,P59,P61,P62,P63,P64, P65,P66,P67,P68,P72,P74,P82
	C7	P6,P7,P18,P52,P53,P54,P55,P57,P58,P69,P70, P71,P73,P75,P76,P77,P78,P79,P80,P81,P83,P84, P85,P86,P87,P88
$\delta = 3$	C1	P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12,P13, P14,P15,P16,P17,P18,P19,P20
	C2	P2,P24,P25,P26,P27,P28,P29,P30,P31,P32,P36
	C3	P3,P21,P22,P23,P33,P34,P35,P37,P38,P39,P40, P41,P42,P43,P44,P45,P46,P47,P48
	C4	P4,P49,P50,P51,P52,P53,P54,P57,P58,P59,P60
	C5	P5,P56,P61,P62,P63,P64,P65,P66,P67,P68
	C6	P6,P69,P70,P71,P72,P73,P74,P75,P76,P87
	C7	P7,P55,P77,P78,P79,P80,P81,P82,P83,P84,P85, P86,P88
$\delta = 4$	C1	P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12,P13, P14,P15,P16,P17,P18,P19,P20,P58
	C2	P2,P24,P25,P26,P27,P28,P29,P30,P31,P32,P36, P43
	C3	P3,P21,P22,P23,P33,P34,P35,P37,P38,P39,P40, P41,P42,P44,P45,P46,P47,P48
	C4	P4,P49,P50,P51,P52,P53,P54,P57,P59,P60
	C5	P5,P56,P61,P62,P63,P64,P65,P66,P67,P68
	C6	P6,P69,P70,P71,P72,P73,P74,P75,P76,P87
	C7	P7,P55,P77,P78,P79,P80,P81,P82,P83,P84,P85, P86,P88
$\delta = 5$	C1	P1,P2,P3,P4,P5,P6,P7,P8,P9,P10,P11,P12,P13, P14,P15,P16,P17,P18,P19,P20
	C2	P2,P24,P25,P26,P27,P28,P29,P30,P31,P32,P36
	C3	P3,P21,P22,P23,P33,P34,P35,P37,P38,P39,P40, P41,P42,P43,P44,P45,P46,P47,P48
	C4	P4,P49,P50,P51,P52,P53,P54,P57,P58,P59,P60
	C5	P5,P56,P61,P62,P63,P64,P65,P66,P67,P68
	C6	P6,P69,P70,P71,P72,P73,P74,P75,P76,P87
	C7	P7,P55,P77,P78,P79,P80,P81,P82,P83,P84,P85, P86,P88

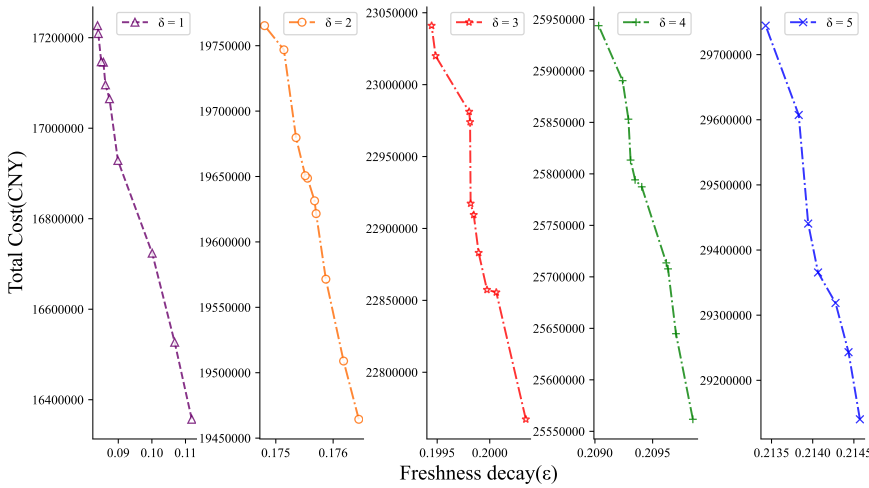

FIGURE 6. The relationship between the size of δ and the total cost and freshness

5.3. **Managerial insights.** (1)The freshness decay of FAP is affected by many factors. Among them, the improvement of logistics efficiency can greatly improve the freshness of FAP. However, with the diminishing marginal effect of logistics efficiency, in order to maintain the high freshness of fresh agricultural products, the logistics cost will increase significantly, as shown in Figure 3 and Figure 6. Therefore, under the condition of acceptable freshness, it is necessary to balance the logistics cost. For example, the acceptable freshness of FAP can be understood through the investigation of factory. And on this basis, a logistics network is established to reduce logistics costs.

(2)The processing time of fresh agricultural products at the collection center is the main factor for their freshness decay. As shown in Figure 6, as the processing time increases, the median freshness drops from 90% to 78.5%, a decrease of 12.8%. Therefore, it is an important way to enhance the freshness of FAp to increase the processing capacity of collection center. With the mechanization and automation of FAP processing in the future, the unit product processing cost of FAP at the collection center will be further reduced, and the processing efficiency will be greatly improved, so as to improve the freshness of FAP. At the same time, it further meets the requirements of processing factory for FAP, and reduces logistics costs.

(3)From the perspective of logistics system optimization, it is necessary to strengthen the research on the integrated optimization of pick, storage and transportation of FAP. Establishing an integrated transportation network for FAP according to the demand of processing factory can improve the integration and intensification of them, reduce their retention time in collection center, improve their freshness and reduce logistics costs. Therefore, this case can be expanded, the corresponding parameters can be modified, and it can be applied to the establishment of other similar FAP logistics networks.

6. **Conclusion and future research.** In this paper, a split pick-up and freshness-constrained FAP logistics optimization problem was studied. A three-layer integrated optimization model of pick, storage and transportation was established. We

considered that the collection can be split and aim to minimize the total logistics cost and freshness decay. At the same time, epsilon+GA (EPGA) and epsilon+SA (EPSA), two solving algorithms were designed for this optimization problem. The pick-storage-transportation of yellow peach in Yanling County, Hunan, China, which is an actual case, to verify and analyze the effectiveness of the method proposed in this paper. The calculation results show that both EPGA and EPSA have good solution quality and efficiency, and EPGA is more effective than EPSA. The experimental results show that EPGA can provide a positive solution for the integration optimization problem of FAP with collection separability and freshness constraints, and has the value of promotion. However, FAP logistics is a relatively complex logistics mode, which not only has more strict requirements on the storage and transportation environment (such as temperature, humidity, preservation, etc.), but also has the timeliness of storage and transportation, and also has the characteristics of diversified logistics links. Therefore, future research will focus on developing optimization methods for collection, storage, and transport vehicle routing with time constraints and requirements. In addition, the logistics optimization research of FAP in this paper is based on a deterministic environment. However, uncertain environments are often encountered in all aspects of logistics, such as the dynamic change of transportation road conditions and demand of processing factory. Therefore, it is also an important research direction to consider the robustness of FAP collection, storage and transportation process under various random factors.

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Appendix. The symbol representation of planting regions, collection center and factory is shown in the following Table 6, 7 and 8.

Table 6: Planting Regions Symbol

Village number	Village name	Village number	Village name
$P1$	Shiziba Village	$P45$	Xinlong Village
$P2$	Yanjia Village	$P46$	Low ridge village
$P3$	Zhongtuan Village	$P47$	Huang Shang
$P4$	Jili Village	$P48$	Gualiao Village
$P5$	Huangsha long village	$P49$	Muwan Village
$P6$	Kanping Village	$P50$	Guancangxia Village
$P7$	Caoping Village	$P51$	Shuixi Village
$P8$	Shiyu Village	$P52$	Shuikou Village
$P9$	Madao Village	$P53$	Xiecheng Village
$P10$	Vegetable village	$P54$	Pinggang Village
$P11$	Jiulong Village	$P55$	Qinglin Village

Village number	Village name	Village number	Village name
$P12$	Yanxi Village	$P56$	Peach Village
$P13$	Xingchao Village	$P57$	Ziyuan Village
$P14$	Panjia Village	$P58$	Baiyuan Village
$P15$	Xitai Village	$P59$	Pulp Village
$P16$	Jiantianzhou Village	$P60$	Xialong Village
$P17$	Tianping Village	$P61$	Three mounted Dragon Village
$P18$	Xiayang town	$P62$	Longxi Village
$P19$	Longsgang Village	$P63$	Nan'an Village
$P20$	Huojia Village	$P64$	Xianping Village
$P21$	Dayuan Village	$P65$	Chalong Village
$P22$	County Institute of Agricultural Sciences	$P66$	Qiutian Village
$P23$	Shangguan Village	$P67$	Banxi Village
$P24$	Pankeng Village	$P68$	Caiping Village
$P25$	Xiaguan Village	$P69$	Tongle Village
$P26$	Cangbei Village	$P70$	Jiufeng Village
$P27$	Shanglao Village	$P71$	Colt Village
$P28$	Xiaoyang Village	$P72$	Yunli Village;
$P29$	Changjiang Village	$P73$	Lingfeng Village
$P30$	Shitou Village	$P74$	Xiaohengxi Village
$P31$	jiudu Village	$P75$	Dahengxi Village
$P32$	Dajiang Village	$P76$	Qingxi Village
$P33$	Shiba Village	$P77$	Nakamura Village
$P34$	Qingshi Village	$P78$	Longtan Village
$P35$	Ankang Village	$P79$	Daoren Village
$P36$	Zhongdong Village	$P80$	Longjing Village
$P37$	Liangtian Village	$P81$	Xintian Village
$P38$	Xiaodong Village	$P82$	Meigang Village
$P39$	Yangqishe Nationality Village	$P83$	Longzha Village
$P40$	Shennong Valley Village	$P84$	Red Star Bridge Village
$P41$	Qingshigang Village	$P85$	Longfeng Village
$P42$	Mihua Village	$P86$	Pingle Village
$P43$	Chexi Village	$P87$	Kangle Village
$P44$	Xiaojiang Village	$P88$	Xinshan Village

Table 7. Collection center symbol table

Collection center number	Collection center name
C1	Xiayang town goods collection center
C2	Mianyang town goods collection center
C3	Shidu town goods collection center
C4	Shuikou Town goods collection center
C5	Longxi Township goods collection center
C6	Xiacun Township goods collection center
C7	Zhongcun Yao Township goods collection center

Table 8. Factory Symbol

Factory Number	Factory Name
$F1$	Nameizi Factory
$F2$	Sweet Lady Factory
$F2$	Guoyaya Factory
$F2$	Greenery Fruit Factory
$F2$	Shi Cheng Cheng Factory
$F3$	Greenery Fruit Factory
$F4$	New Friend Factory
$F5$	Taochuan Town Huashan Factory

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