Research on Fresh Produce Delivery Scheduling Problems under the Perspective of Community E-commerce

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Abstract. This paper addresses the challenges associated with the high costs and logistical difficulties in the distribution of fresh agricultural products from the perspective of community e-commerce. The paper takes the perspective of merchant scheduling and integrates a classical vehicle scheduling model. The study meticulously examines the various costs associated with the distribution process, encompassing fixed costs, transportation costs, refrigeration costs, storage costs and time subsidies. A vehicle routing optimisation model was developed with the dual objectives of cost control and product quality assurance. The use of a genetic algorithm for analysis and solution indicates that this approach can achieve superior cost efficiency and more optimal delivery routes. The results not only confirm the validity of the model and the effectiveness of the solution algorithm, but also provide theoretical underpinnings and viable optimisation strategies for analogous route optimisation challenges. This research has significant reference value and practical relevance for improving delivery efficiency and cost management in community e-commerce.

Keywords: Community e-commerce, Fresh agricultural products, Delivery scheduling, Genetic algorithm.

1. Introduction

The acceleration of social and economic development, the exponential growth of Internet technology, and the relentless pursuit of enhanced logistics and transportation operations have collectively elevated the quality of life for individuals worldwide [1]. The demands of consumers for quality, convenience and personalisation in their lives are increasing, which has led to the online shopping phenomenon becoming an indispensable part of daily life. Nevertheless, the traditional retail industry is confronted with mounting costs and intensifying competition as a consequence of the Internet, which has led to the necessity for an urgent transformation and modernisation. In this context, community e-commerce has emerged as a novel phenomenon, closely connecting community residents with goods and services through Internet technology, thereby providing a convenient and efficient shopping experience.[2]. As an innovative business model, community e-commerce has the potential to reduce costs and improve efficiency, while simultaneously facilitating the growth of traditional retail.

The "Dianshubao" e-commerce database indicates that the transaction scale of fresh food e-commerce is anticipated to reach 642.76 billion yuan in 2023, representing a 14.74% increase compared to the previous year. The user base of the community group buying industry is projected to reach 678 million in 2023, representing an 8.3% increase from the previous year. The transaction volume of fresh food e-commerce is anticipated to reach 322.8 billion yuan, a 53.71% surge from the previous year. In the first half of 2023, urban residents' food consumption expenditure is projected to reach 1.0594 trillion yuan, with fresh food e-commerce accounting for 27.6% of food consumption expenditure. Overall, the data indicates an upward trend in group buying in community e-commerce[1].

[1] Source of data: www.100ec.cn

As a significant sector of community e-commerce, the distribution and scheduling of fresh agricultural products is of paramount importance [3]. As businesses expand, the importance of optimising delivery routes, ensuring accurate delivery times and maintaining the freshness of goods in the distribution of fresh produce becomes increasingly significant. These issues not only affect the customer experience and satisfaction, but also directly impact the quality of fresh agricultural products and the reputation of community e-commerce.

This paper reviews the academic literature and research progress at two levels: community e-commerce vehicle distribution and fresh agricultural product vehicle distribution. It is based on the research direction of fresh agricultural product distribution planning from the perspective of community e-commerce.

The research on community e-commerce vehicle distribution indicates that mature e-commerce platforms encounter challenges in expanding their user base. This shift in competition from "incremental competition" to "inventory competition" necessitates that platforms expand their business scope across borders. Community e-commerce utilises a three-level warehousing and distribution system comprising a central warehouse, network station and group leader. It employs the method of "online reservation and order + offline pickup the next day", integrating online shopping with offline pickup services. It is distinguished by a high degree of division, an efficient process of customer acquisition, the expansion of social functions, and the rapid dissemination of information. Nevertheless, the logistics distribution sector is confronted with a number of challenges, including an imbalance between supply and demand, a lack of timely fulfilment, a reduction in convenience for customers, and an unsatisfactory user experience.[4-5].

The field of research on the distribution of fresh produce focuses on the optimisation of routes and the control of costs. Related studies include the establishment of cold chain logistics route optimisation models, the reasonable setting of relay points to minimise total cost, and dynamic design models to achieve total cost minimisation and customer satisfaction maximisation. Furthermore, research encompasses temperature monitoring, food safety assurance, and cold chain logistics system optimisation. Researchers have put forth a number of optimisation schemes for the practical issues inherent to the distribution of fresh produce. These include joint distribution schemes, front warehouse + community distribution centre models, which are designed to eliminate technical bottlenecks in the cold chain logistics distribution system and improve product quality and customer satisfaction. [6-7].

The existing literature on vehicle scheduling issues addresses these issues from two distinct perspectives: that of community e-commerce and that of fresh agricultural products. However, there are few studies that integrate these two perspectives. In light of the above literature, this paper combines the two perspectives and studies the distribution and scheduling of fresh agricultural products from the perspective of community e-commerce. The study considers the full range of costs associated with the distribution and scheduling of fresh agricultural products in the context of community e-commerce. These include fixed costs, transportation costs, refrigeration costs, cargo storage costs, and time subsidy costs. A route optimization model is developed to support the research on the distribution and scheduling of these products.

2. The fundamental of the Vehicle Routing Problem with Time Windows

2.1. Background and Assumptions of the Vehicle Routing Problem with Time Windows

The vegetable delivery platform serves as an illustrative example. Its primary objective is the sale of fresh agricultural products, and it is dedicated to providing consumers with a comprehensive assortment of products. In order to attract and retain users, the platform employs an efficient centralised network warehouse delivery model for order distribution. For orders placed before midnight, the platform dispatches dedicated vehicles from the central grid warehouse with a commitment to deliver the orders to the appropriate pick-up points before a specified time the following day. The aforementioned pick-up points are typically situated at community railway stations, community supermarkets, or other small businesses that facilitate the convenient collection of orders by consumers.

During the delivery process, the platform coordinates the departure of a number of trucks from the Central Grid Warehouse at regular intervals, with the objective of delivering fresh produce to a number of surrounding collection points. The locations and requirements of these collection points are known. At this juncture, the Central Grid Warehouse devises a rational plan for the delivery routes of the trucks, with the objective of ensuring that the products are delivered to the collection points within the specified time frame and subsequently returned to the Grid Warehouse. When planning the routes, the platform considers various factors, including the maximum load capacity of the trucks, the specified time windows, and the location and demand of the collection points. By optimising route planning, the platform is able to achieve controllable total delivery costs while meeting the needs of the collection points and customer satisfaction. The following assumptions are made in this model:

1. The number of vehicles belonging to the network warehouse is sufficient and homogeneous. The vehicles are subject to weight limits, and the total weight of products required by each collection point on each delivery route is less than or equal to the maximum vehicle load.
2. Each delivery vehicle commences its journey at the Central Grid Warehouse, completes the delivery service at the designated collection point, and then returns to the Grid Warehouse.
3. Each collection point is serviced on a one-time basis.
4. The vehicles maintain a constant speed throughout the delivery process.
5. It is imperative that the service time for all collection points by the vehicles does not exceed the specified time.
6. All customers are expected to arrive at their respective collection points at the specified time to collect their goods.
7. All customers at the same collection point are subject to the same level of acceptance with regard to damage to goods.

As shown in Table 1, each variable and its interpretation is known.

Table 1. Variable Definition

symbols	Description of symbols
V	Set of grid warehouses and pickup points, $V=\{0,1,2,\cdots,n\}$
W	Set of vehicles $W=\{1,2,\cdots,A\}$
U_i	Set of customers at pickup point $U_i=\{1,2,\cdots u_i\}$
f_a	Fixed usage cost of vehicle a
c_{ij}^a	Unit distance cost for vehicle a traveling from pickup point i to j
q_{ik}	Demand of the jth customer at pickup point i
Q	Product weight per vehicle delivery
d_{ij}	Euclidean distance between points i and j
t	Delivery time required for the route
t_i	Arrival time of the vehicle at pickup point i
bs_i	Service start time at pickup point i
ts_i	Service time for pickup point i
ts_i'	Total service time at other points on the route before arriving at point i
α_1	Early arrival time cost for the vehicle
α_2	Late arrival time cost for the vehicle
c_r	Refrigeration cost per unit time during transportation
c_r'	Refrigeration cost per unit time during unloading service
c_d	Storage cost per unit weight of products
x_{ij}^a	1 if vehicle a travels on the route (i,j), otherwise 0
y_i^a	1 if pickup point i is served by vehicle a, otherwise 0

2.2. Cost function analysis

The model presented in this paper is analysed as follows:

(1) Fixed costs

When the central grid warehouse dispatches each truck for distribution, it must bear the fixed costs associated with the purchase or lease of the vehicle, the remuneration of the driver, the wear and tear of the vehicle, and so forth. In order to facilitate the calculation process, the aforementioned costs have been set as fixed values. In the event that the central grid warehouse deploys vehicles for the purpose of distribution, the fixed cost can be expressed as follows:

$$c_1=\sum_{a=1}^{A}\sum_{i=1}^{n}x_{0i}^a f_a \tag{1}$$

(2) Transport costs

The costs incurred for fuel consumption and maintenance of vehicles are directly proportional to the mileage travelled. Consequently, the transport cost of a vehicle can be expressed as follows:

$$c_2=\sum_{a=1}^{A}\sum_{i,j=0}^{n}c_{ij}^a d_{ij}x_{ij}^a \tag{2}$$

(3) Refrigeration costs

The cost of refrigeration encompasses the expenditure incurred by the vehicle to maintain a low temperature during transport, in addition to the supplementary energy supplied by the refrigeration system during unloading, as the doors are opened and the temperature within the compartment rises. Consequently, the cost of refrigeration of a vehicle during transport can be expressed as follows:

$$c_{31} = c_r \sum_{a=1}^{A} \sum_{i,j=0}^{n} x_{ij}^{a} \frac{d_{ij}}{v} \tag{3}$$

During the process of unloading, the cost of refrigeration of the vehicle can be expressed as follows:

$$c_{32} = c_r{}' \sum_{a=1}^{A} \sum_{i,j=1}^{n} y_i^a ts_i \tag{4}$$

Consequently, the total cost of refrigeration can be expressed as follows:

$$c_3 = c_r \sum_{a=1}^{A} \sum_{i,j=1}^{n} x_{ij}^{a} \frac{d_{ij}}{v} + c_r{}' \sum_{a=1}^{A} \sum_{i,j=1}^{n} y_i^a ts_i \tag{5}$$

(4) Cargo storage cost

Following the delivery of the fresh products by the delivery vehicle to the outlets, the latter are required to pay the storage cost to the former. This cost is typically proportional to the quantity of goods stored. Consequently, the storage cost paid by the platform in collaboration with the outlets can be expressed as follows:

$$c_4 = \sum_{i=1}^{n} \sum_{k=0}^{u_i} c_d q_{ik} \tag{6}$$

(5) Time subsidy costs

In the event that the delivery vehicle fails to arrive within the anticipated timeframe specified by the pickup outlet, the outlet's satisfaction declines, resulting in the imposition of a time allowance cost. The magnitude of this cost is contingent upon the extent of the discrepancy between the vehicle's actual arrival time and the outlet's desired time window. Consequently, the time subsidy cost can be expressed as follows:

$$c_5 = \sum_{i=1}^{n} (\alpha_1 \max\{e_i - t_i, 0\} + \alpha_2 \max\{e_i - l_i, 0\}) \tag{7}$$

2.3. Modelling the vehicle routing problem with time windows

In conclusion, the research model of the fresh produce delivery scheduling problem from the perspective of community e-commerce, as explored in this paper, is presented below.

$$MinC = c_1 + c_2 + c_3 + c_4 + c_5 \tag{8}$$

$$\sum_{a=1}^{A} \sum_{i=1}^{n} x_{0i}^{a} \le A \qquad (\forall a \in A, i \in V / \{0\}) \tag{9}$$

$$\sum_{a=1}^{A} \sum_{i=1}^{n} y_i^a = n \tag{10}$$

$$\sum_{a=1}^{A} y_i^a = 1 \tag{11}$$

$$\sum_{i=1}^{n} x_{0i}^{a} = \sum_{i=1}^{n} x_{i0}^{a} \le 1 \qquad (\forall a \in W) \tag{12}$$

$$\sum_{i=1}^{n} \sum_{k=1}^{u_i} y_i^a q_{ik} \le Q \qquad (\forall a \in W) \tag{13}$$

$$t_j = \sum_{a=1}^{A} \sum_{i=1}^{n} x_{ij}^{a} [\max(t_i, E_i) + ts_i + \frac{d_{ij}}{v}] \qquad (j \in V / \{0\}) \tag{14}$$

$$bs_j = \sum_{a=1}^{A} \sum_{i=1}^{n} x_{ij}^{a} [\max bs_i + ts_i + \frac{d_{ij}}{v}, E_j] \qquad (j \in V / \{0\}) \tag{15}$$

$$E_i \le bs_i \le L_i \le T \qquad (\forall i \in V / \{0\}) \tag{16}$$

Equation (9) indicates that the central grid warehouse has sufficient vehicles to deliver products. Equation (10) indicates that each self-pickup outlet is serviced. Equation (11) indicates that each self-pickup outlet is serviced only once. Equation (12) indicates that the vehicle's trajectory is a closed loop, which starts from the central grid warehouse, finishes the delivery, and finally returns back to the central grid warehouse. (13) indicates that the demand for the self-pickup outlets serviced by a unit of the vehicle does not exceed the vehicle weight limit. (14) indicates that the vehicle arrives at the self-pick-up outlet time. (15) indicates that the vehicle starts service at the self-pick-up outlet time. (16) indicates that the vehicle start service time must be within the acceptable time window of the self-pick-up outlet and must be before the time of the hour.

3. Genetic Algorithm for Vehicle Routing Problem Based on Time Window

3.1. The establishment of simulation model

The big data prediction model of consumer electricity consumption is implemented by MATLAB software.

1. Chromosome coding

In this paper, the natural number coding method is employed to encode the chromosome. The following rules are employed for the encoding of the chromosome: the length of the chromosome is equal to the number of pick-up outlets plus the number of vehicles minus one; the use of natural number coding is employed, whereby specific numbers represent the central grid silo (i.e., the starting point of the transport vehicle), while the remaining numbers represent the pick-up outlets. Furthermore, the pick-up outlets are divided into different segments, with each segment representing one sub-path (served by one transport vehicle).

2. Initial solution generation and population initialisation

In this paper, the following methods are employed to generate higher-quality initial solutions.

Step 1: A random selection of outlets should be made, and a sequence of outlets generated.

Step 2: initialize the vehicles and traverse the sequence. It is recommended that the initial vehicle be used to traverse the sequence of self-pickup outlets in order.

Step 3: The sequence of outlets is then traversed and paths are assigned. The outlets are then placed in the initial path and the load constraint is evaluated to ascertain whether it is satisfied. Should this be the case, the operation may be continued; otherwise, the process should be terminated and the user directed to step 5.

Step 4: Assign and insert dots. If the current path is devoid of dots, it should be placed directly into the path. If the number of dots in the current path is one, the insertion position should be determined according to the size of the left time window of the dots. In the event that the number of dots in the current path is one, there will be a single insertion point. It is necessary to iterate through the insertion points and confirm whether the left time window of the dots can be inserted between the left time windows of the dots before and after the insertion position. If this is the case, the dot should be inserted into the position. If it cannot be inserted, it should be inserted at the end of the path. In the event that this is not the case, the aforementioned element should be inserted at the end of the path.

Step 5: Path adjustment and new vehicle assignment. In the event that the initial path does not satisfy the load constraint, it is necessary to store the outlets visited by the first vehicle before it visits the outlets. This should then be updated and the process should be repeated at step three. Until all the outlets have been traversed, the initial solution can be generated. The natural numbers greater than the number of outlets are then used to represent the central grid bins between the sub-paths formed by the initial solution. This connects the sub-paths together to form a population of individuals. The above method is then repeated to generate a certain size of the initial population.

3. Adaptation Function

In this paper, the objective is to identify the minimum value of the objective function. To this end, the fitness function is defined as the inverse of the objective function, ensuring that a smaller value of the objective function corresponds to a higher value of fitness.

4. Selection operation

This paper employs the roulette selection method, wherein the population generation gap rate is set at 90%. This means that, in each selection operation, 90% of the individuals in the current population are selected based on their fitness values. The remaining 10% are comprised of individuals with the best fitness values in the previous generation of the population. This approach ensures that the optimal individuals of each generation of the population are not lost during the evolutionary process. Subsequently, individuals are selected according to their fitness values for subsequent crossover, mutation and local search operations.

5. Crossover operation

In this paper, we select the crossover method. Two crossover points are randomly selected, and the parent sequence is divided into three parts based on these points. The first part is the genes before the first crossover point, the second part is the genes between the first and second crossover points, and the third part is the genes after the second crossover point. The crossover segment of the first parent is inserted before the point of the second parent, and the crossover segment of the second parent is inserted before the point of the first parent. The duplicated genes resulting from the insertion are deleted, thereby generating two new offspring individuals.

6. Mutation operation

In this paper, two-point mutation is adopted, and the specific operations are as follows:

(1) Two distinct positions on the chromosome are randomly selected as mutation points.

(2) The gene values at the two mutation points are exchanged, thereby exchanging the customers represented at these two positions.

The introduction of two points of mutation enables the generation of a novel individual that differs from the original in terms of genetic structure. This may result in an enhanced fitness. The mutation operation enables the algorithm to escape from local optimal solutions and enhance its capacity for global search.

7. Termination conditions

The termination condition employed in this paper is the achievement of a predefined number of evolutionary generations. Consequently, when the evolutionary algebra of the algorithm attains the predefined maximum value, the algorithm terminates and outputs the current optimal solution. Should the predefined maximum value not be reached, the algorithm will continue to evolve in order to identify a superior solution. By establishing appropriate termination conditions, the algorithm is able to identify the optimal solution in a limited time[8-9].

3.2. Parameter settings

We construct the following self-pickup network information as an example for numerical experiments. In the example, there are 1 central grid warehouse and 10 self-pickup outlets, and the number of customers in each self-pickup outlet is 15, 18, 10, 20, 15, 25, 15, 10, 20, 15. The maximum number of vehicles that can be dispatched from the central grid warehouse is 5. The location of each self-pickup outlet, the corresponding number of customers, and the demand are known, as shown in Table 2.

Table 2. Data on self-service outlets

Pick-up point serial number	x-axis	y-axis	Number of clients	Total procurement ($\times 10^{-1}$ tonnes)
1	5	10	15	28
2	15	15	18	35
3	15	10	10	25
4	25	15	20	42
5	10	15	15	35
6	25	10	25	45
7	20	20	15	35
8	15	25	10	25
9	20	5	20	45
10	10	5	15	37

In the process of vehicle transport and door opening and unloading service, the unit cooling cost is 30 yuan/hour and 40 yuan/hour; the unit storage cost is 10 yuan/hour; the time cost of vehicle arriving early is 10 yuan/hour; and the time cost of delayed arrival is 20 yuan/hour. The central grid warehouse sends homogeneous vehicles to carry out distribution services for the self-pick-up outlets, assuming that the average speed of the vehicle is 40 km/hour, the maximum load is 1.5 tonnes, the fixed cost of vehicle use is RMB 200, and the cost of transport per unit of travel is RMB 4/km.

4. Result

As the data results will vary after each run, the population size was set to 50, and the numerical experiment was conducted for 100 iterations to generate the path results, with roughly similar types of iteration curves, as shown below:

Vehicle number selected: 2 4 5, total cost: RMB 5,117.4795; Vehicle No. 2 serves customers: 10 3 1; Vehicle No. 4 serves customers: 8 7 2 5; Vehicle No. 5 serves customers: 9 6 4.

As the population iterates, the optimal solution is gradually derived as shown in Fig. 1. The path optimisation of the optimal solution is shown in Fig. 2

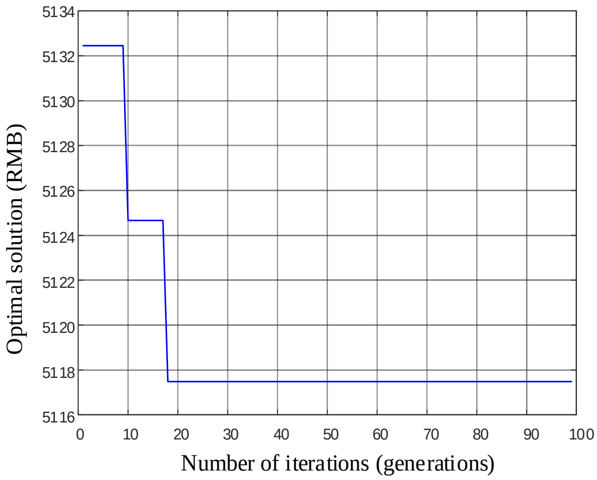

Figure 1. iteration curve

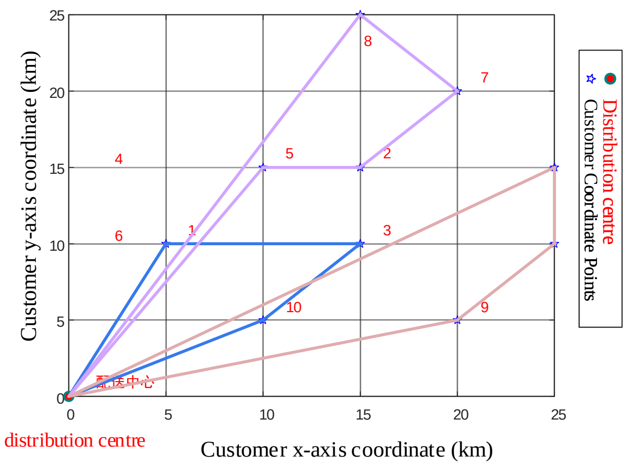

Figure 2. Schematic diagram of customer Coordinates

5. Discussions

5.1. Management Strategies

5.1.1. Optimize Vehicle Allocation for Delivery

Vehicle Capacity Matching: Select vehicles based on the size and weight of the goods to maximize loading efficiency and avoid overloading or underloading[10].

Dynamic Route Optimization: Use real-time traffic data and delivery status to adjust routes, avoiding congestion and reducing time and costs[6].

5.1.2. Enhance Logistics Algorithms

Initial Population Settings: Optimize the initial settings in genetic algorithms to ensure quick convergence to an optimal solution[7].

Advanced Optimization Techniques: Use techniques like simulated annealing, particle swarm optimization, and ant colony algorithms for better performance on specific problems.

Multi-objective Optimization: Consider factors like cost, time, service quality, and customer satisfaction to find the best trade-off solution.

5.2. Legal Issues

5.2.1. Transportation and Delivery

Food Safety Requirements: Vehicles and containers must meet food safety standards to prevent contamination, kept clean, and regularly disinfected.

Cold Chain Logistics: Use cold chain systems for refrigerated or frozen goods, maintaining constant temperatures and using temperature recording devices.

Return and Exchange Policies: Establish clear policies for returns and exchanges, ensuring consumer rights are protected.

5.2.2. Product Quality

Refrigerated Storage: Ensure all refrigeration facilities meet national food safety standards to prevent spoilage and bacterial growth.

Timely Pickup Notifications: Notify customers promptly to prevent prolonged storage issues, ensuring the product's safety and quality. Failure to do so may entitle consumers to compensation.

6. Conclusions

This paper delves into the scheduling and dispatching issues of fresh agricultural products under the community e-commerce model. Due to the perishable and fragile nature of fresh products, ensuring timely delivery and maintaining product quality are crucial factors that distinguish a platform from its competitors. To address these issues, an optimization model was developed, aiming to enhance transport route efficiency, ensure quality, and control costs.

The study, focused on the unique challenges of fresh product delivery in the community e-commerce model, leverages big data and artificial intelligence technologies. By analyzing pickup point data and customer order data and utilizing genetic algorithms for precise route planning, delivery efficiency was significantly improved, operational costs were reduced, and resource optimization and utilization were promoted. This not only enhanced overall delivery operations but also ensured the quality and safety of fresh agricultural products.

By implementing reasonable vehicle allocation for delivery and continuous optimization of logistics algorithms, community e-commerce platforms can significantly enhance their operational efficiency in scheduling and dispatching fresh agricultural products. Selecting appropriate vehicle types, such as refrigerated trucks for meat and frozen goods, and utilizing dynamic routing technology to adjust routes in real-time helps avoid congestion and reduce transportation costs. Advanced optimization techniques and multi-objective optimization algorithms ensure efficient logistics processes by considering multiple factors such as cost and time simultaneously.

From a legal perspective, strict adherence to food safety laws, including cold chain logistics regulations, is crucial for ensuring product quality and safety. Compliance with return and exchange policies and consumer rights protection laws is essential. Implementing rigorous refrigerated storage measures, promptly notifying customers for pickup, and assuming compensation responsibilities within the legal framework enhances customer trust and satisfaction.

Community e-commerce platforms can significantly improve the efficiency and quality of fresh produce scheduling and distribution by adopting effective management strategies and resolving related legal issues, thereby providing consumers with quality services. This paper provides strong support for community e-commerce platforms in the scheduling and distribution of fresh produce, improving overall operational efficiency and ensuring product quality.

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