Research on Vehicle Routing Optimization for Rural Express Joint Distribution

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Abstract. This paper studies the problem of rural express logistics distribution, considering the dual demand of rural customers, the diversity of agricultural products, the dispersion of rural customer gathering places and so on. Optimize the joint delivery of rural express by introducing the model of vehicle routing problem with split deliveries and pickups (SVRPPD). The objective of optimization is to minimize the total cost of distribution system. According to the characteristics of the model, a competitive decision algorithm is designed to solve the problem. Finally, the practicability and effectiveness of the model and algorithm are verified by an example.

1. Introduce

In recent years, the development of logistics industry has made rapid progress. With the development of rural e-commerce, rural logistics also ushered in high-speed development. Rural logistics is a concept relative to urban logistics, which plays an important role in promoting the circulation of rural commodities and meeting people's living and shopping needs[1]. However, due to many problems in the current rural logistics, the distribution cost of rural logistics is high and the distribution efficiency is low. Therefore, the distribution of rural logistics has been restricting the development of rural economy.

The key to solve the problem of rural logistics is to analyze the characteristics of rural logistics and reasonably plan the vehicle routing of rural logistics, and to solve the vehicle routing problem of rural logistics (VRP). Based on the analysis of rural logistics, the following characteristics are put forward:

1) Non concentrative

An important feature of rural logistics is non-centralization, which is determined by the decentralization of various agricultural products and rural villages. Different agricultural production areas are different, villages are generally near the production area, so rural logistics has a certain degree of non-centralization.

2) Larger cost

At present, rural logistics mainly focuses on the transportation of agricultural products. However, due to the long route and the shortcomings of transportation tools, agricultural products are easy to rot, not easy to store and suffer serious losses. Therefore, compared with urban logistics, the cost of rural logistics is larger.

3) Complexity

Firstly, because of the abundant rural products, there are many kinds of rural logistics and a large number of transportation, so the requirements for distribution vehicles are more complex. Secondly, with the development of rural economy and the improvement of living standards, rural logistics has the dual demand of collecting goods and delivering goods, which seriously aggravates the complexity of
rural logistics.

Analysis of the Characteristics of Rural Logistics. For the study of rural logistics joint distribution, we should reasonably determine the number, layout, scale and function of logistics nodes, and vigorously promote the whole network layout of rural logistics network nodes[2]. Improve the centralization of rural distribution points. With joint distribution as the strategy and optimization of vehicle routing as the focus, the rural express logistics is improved. Shorten the distribution time and reduce the decay of agricultural products due to the long distribution time, thus reducing the cost of rural logistics. Because of the limitation of vehicle load, type and the dual demand of rural distribution points, if only the general vehicle routing model is considered, it can’t be rationally optimized in terms of resource utilization, transportation time and transportation cost. To deal with these problems, the vehicle routing with split deliveries and pickups(SVRPPD) can achieve multiple visits to customers, reduce the waste of vehicle resources, improve vehicle loading rate, shorten the total vehicle routing, and make vehicle routing planning flexible. Finally, rural logistics system and vehicle routing system are effectively combined.

1.1. The vehicle routing problem with split deliveries and pickups
In general vehicle routing problem(VRP), each customer only has delivery or pickups demand, that is, pure delivery (pickups) vehicle routing problem. In practice, there are distribution points with double demand, which results in pickups and delivery problems (VRPPD). Whether VRP or VRPPD, the minimum cost of distribution is used to meet all the needs of customers. At present, most of the vehicle routing research is aimed at the demand of each customer point can only be served by one vehicle, that is, the problem type of demand can’t be split. However, it is not uncommon to be separated and transported according to the needs of customers. For example, due to the diversity of agricultural products, different products need different means of transport and handling equipment. Classified transportation can improve the efficiency of logistics operations. So there's the vehicle routing problem with split deliveries and pickups(SVRPPD).

The existing theoretical research and facts have proved that SVRPPD is conducive to making full use of vehicle loading capacity and reducing vehicle driving costs. Mitra[3][4]studied the vehicle routing optimization problem with demand separability, which laid a foundation for the development of dual demand separability. WANG K F deeply studies the problem characteristics of VRPSDPD, which provides a more detailed theoretical basis for the research[5][6][7]. Tang G C uses VRPSD model to solve real third party logistics cases, considering the time window limitation. VRPSDPD with time window is proposed VRPSDP with time windows, VRPSDPDPTW ][8][9]. 2017, Wassan presents the he vehicle routing problem with divisible deliveries and pickups (VRPDDP) problem to scholars. VRPDDP is a special case of SVRPPD[10]. Nagy proves that the vehicle routing problem with split deliveries and pickups path can effectively reduce costs and even more importantly reduce the number of vehicles needed when there is a large customer cluster and a large demand for customer delivery. At the same time, when the demand for goods collection and delivery changes in a large range, the length of the route and the number of vehicles will be greatly reduced[11]. In view of this, the model of joint distribution is implemented for rural distribution points. At the same time, SVRPPD is combined with rural express distribution. A mathematical model of SVRPPD is constructed with the goal of minimum total distribution cost. A competitive decision algorithm is designed according to the characteristics of the model. An example is used to prove the effectiveness of the model for rural logistics. Hope to provide reference for rural logistics enterprises.

2. Problem description
Traditional rural logistics is distributed separately by multiple express enterprises in an independent distribution network (Figure 1). Each express delivery enterprise has its own distribution centre, which distributes the needed distribution points separately. Each distribution vehicle starts from the distribution centre, completes the distribution demand of each distribution point in turn, and then returns to the distribution centre. Such a distribution mode, so that the overall efficiency of distribution, not only
increase the number of vehicles invested, but also lead to serious no-load vehicles. If rural express enterprises integrate, share a distribution centre, implement joint distribution, and combine SVRPPD routes to distribute all distribution points (Figure 2). Vehicles start from the distribution centre to each distribution area for the task of collecting and delivering goods. According to the demand of collecting goods and delivering goods at each distribution point, the vehicle routing is optimized to reduce the distribution cost of each express enterprise and improve the efficiency of rural logistics.

The common distribution route optimization of rural express logistics can be defined as follows:
1) Common Distribution Centre Location Known;
2) The demand for pickups and delivery at each distribution point is known;
3) All vehicles leave the same distribution centre and eventually return to the centre;
4) All vehicles have the same loading capacity. The actual loading capacity of the vehicle should not exceed the maximum loading capacity of the vehicle;
5) Each distribution point can simultaneously have two kinds of demand for goods pickups and delivery, and any type of demand may be larger than the vehicle loading capacity;
6) According to the total demand of each distribution point, the vehicle can serve it more than once;
7) No Time Window and Maximum Path Distance Limitation;
8) Set the number of vehicles K as the known parameter;

\[
K = \left\lfloor \frac{\max\{D, P\}}{Q} \right\rfloor
\]

In the formula: D is the total delivery volume; P is the total pick-up volume; Q is the maximum loading capacity of the vehicle.

3. Model Construction
Let us introduce the following notation.
- \(i, j\): set of distribution centre and all distribution points: \(\{i, j\} = \{0, 1, \ldots, n\}\);
- \(k\): set of Vehicle labeling;
- \(K\): set of Total number of vehicles used;
- \(Q\): vehicle capacity;
- \(D_j\): the total demand for transportation from the distribution centre to customer \(j\);
- \(P_j\): the total demand for pickup goods at customer point \(J\) and sending them back to the distribution centre;
- \(C_{ij}\): the distance from point \(i\) to point \(j\) of a vehicle;
- Decision variables
  - \(x_{ijk}\) = 1 , if vehicle \(k\) travels directly from point \(i\) to point \(j\) and \(x_{ijk} = 0\) otherwise;
  - \(y_{ij}\): pickup load moved from point \(i\) to point \(j\);
  - \(z_{ij}\): delivery load moved from point \(i\) to point \(j\)
Here we will briefly explain this formula line by line.

(1) Minimizing the total distance traveled by vehicles.

(2)-(3) Ensure that all customer requirements are met.

(4)-(5) Vehicles start with zero pickup load and finish with zero delivery load.

(6) That the number of times a vehicle visits a point is equal to the number of times it leaves that point.

(7) Represents that each vehicle leaves the distribution centre only once and eventually returns to the distribution centre.

(8) Maximum capacity constraint.

(9)-(11) Set $x_{ijk}$ as 0–1 and $y_{ij}/z_{ij}/x_{ijk}$ as nonnegative variables.

4. Algorithm design

4.1. CDA algorithm

It is known that SVRPPD is a NP-hard problem. At present, most scholars use heuristic algorithm to solve SVRPPD problem. In the literature[12], constructive heuristic algorithm is used, which is mainly solved by cluster-first-route-second method. In the clustering stage, scholars generate the initial path scheme through various greedy algorithms, and then optimize the solution by combining the shortest path and intelligent algorithm.
Competitive decision-making algorithm is an optimization algorithm based on the analysis of various competition mechanisms and decision-making principles of the natural biological world, especially human beings, and the characteristics of competition to create optimum and decision-making results[14]. Competition can retain the resources with advantages and eliminate those resources with disadvantages, which shows that competition can play an optimized role.

The earliest CDA was proposed by Ning and Ma to solve CVRP problems[15]. In the CVRP problem, each customer point has only a single demand, and the delivery or pickups demand is not greater than the capacity of the vehicle, and the vehicle only serves the customer point once. Ning and Ma adopt two-stage method to solve CVRP. The first stage is to cluster customers. Customers are divided into several clusters, and the aggregate demand for goods collection and pick-up in each cluster is not greater than the vehicle capacity. In the second stage, the path optimization problem is solved for each cluster.

For SVRPPD, Competition decision algorithm is used to solve the problem in two stages. In the first stage, Determine the number of vehicles required and the customers that each vehicle must visit. In the second stage, the route of each vehicle is determined. The basic flow chart is shown in Figure 3.

**Figure 3. Competition decision flow chart.**

### 4.2. CDA algorithm applied to SVRPPD

The concrete steps are as follows:

Step 1: Initialize the layout

Initially, only one vehicle is allowed to serve customers on each distribution route, and the competitiveness of each vehicle to all customers is equal. Considering the large quantity and variety of distribution products, According to the literature[16], in order to make effective use of the capacity of distribution vehicles, and do not need to limit the number of vehicles. The following methods are specified as the initial layout.

- Initial layout of vehicle routing in two stages
  - In the first stage, if there are customers whose demand for collecting goods and delivering goods is greater than the capacity of vehicles on the customer set, the vehicles will go to the customer point to deliver the goods, pick up the goods at that point, and return to the depot with the full load. The cycle is executed in such a way that all customer points require less than the vehicle capacity for collecting and delivering goods.
  - In the second stage, the updated customers are assigned to the vehicles. Suppose that before vehicle i comes out of the depot, it is necessary to find the customer with the greatest demand among the remaining customers, assign the customer to vehicle i, and then update the status of customer h and vehicle i. Then continue to find a customer hh nearest to customer h and assign it to vehicle i. Under the
principle of greed, meet the gathering and delivery needs of customer hh. Then update the status of customer hh and vehicle i.

Step 2: Competitive decision-making

For the competitiveness function. The competitiveness of vehicle i to customer j is expressed as power (i, j), which represents the distance between vehicle i and customer j.

For the decision function, if there are three conditions at the same time, we can redistribute customer j to vehicle ii, and vehicle i does not need to visit customer j again. These three conditions are as follows:

1) Vehicle i Service Customer j
2) Power(ii,j)<Power(i,j)
3) Vehicle ii can satisfy the delivery and pickups requirements of the first customer j assigned to Vehicle i

These three conditions show that Vehicle ii can replace Vehicle i to serve customer j. The above rules are called decision functions. Under the operation of decision-making function, no vehicle can extract resources from other vehicles. Therefore, competitive decision-making has reached a balance.

Step 3: Distribution and competition of resources

According to the above initialization layout, competitiveness function and decision function, the distribution points of vehicles need services are determined, so that the competition decision can be balanced.

Step 3.1: Eliminate redundant or improper resources

When the competitive decision is balanced, if a customer h is allocated to vehicle i and vehicle j, and power(i, h) < power(j, h). Although no vehicle can recover resources, for other vehicles in this state, we can use the following two methods to break the balance.

Method1: Allow vehicle k to serve customer q at the same time as vehicle i, and meet customer q's needs as much as possible, in order to increase vehicle i's remaining distribution capacity and vehicle remaining space

Method2: Vehicle l and vehicle j are allowed to serve customer h at the same time, and to meet customer h's needs as much as possible, in order to reduce customer h's demand for goods collection and delivery.

Execution methods 1 and 2., if the remaining delivery capacity and vehicle space of Vehicle i can meet the needs of customer h allocated to Vehicle j, then customer h is assigned to vehicle i. Vehicle i extracts customer h from vehicle j.

Step 3.2: Exchange of resources

Under the equilibrium of competitive decision-making, it is assumed that customer h is allocated to vehicle i, while customer g is allocated to vehicle ii , and power (i, g) +power (ii, h) < power (i, h) +power (ii, g) remains unchanged. Then, it checks whether the remaining inventory and delivery capacity of vehicles i and ii can meet the needs of each other when resource exchange occurs. If i and ii can meet the demand, then exchange resources; otherwise, no exchange will be carried out.

Step 3.3: Determine if there are better exchange rules

If there is a resource exchange between competitors that keeps the current state in equilibrium and makes the solution better, then the exchange is carried out until there is no such exchange, otherwise the competition of other rounds will continue.

Step 4: Output one or more of the best results obtained through competitive decision-making.

5. Example

5.1. Example Introduction

Take Wuzhi County of Jiaozuo City as an example. According to the survey, there are one county logistics centre and 12 township logistics centres in Wuzhi County.

The county logistics centre is regarded as distribution centre, and the township-level logistics centre is regarded as distribution point. The longitude and latitude coordinates of 12 distribution points and the demand of collecting and delivering goods are shown in Table 1.
Table 1. Location of distribution points and demand for delivery and pickups (daily).

| Distribution point | X       | Y       | D/n  | P/n  |
|------------------|---------|---------|------|------|
| 1                | 113.60268 | 35.034315 | 220  | 408  |
| 2                | 113.592816 | 35.069036 | 211  | 475  |
| 3                | 113.517466 | 35.058238 | 197  | 405  |
| 4                | 113.522784 | 35.084604 | 227  | 480  |
| 5                | 113.516523 | 35.143931 | 205  | 467  |
| 6                | 113.360577 | 35.050784 | 152  | 474  |
| 7                | 113.353247 | 35.076016 | 156  | 423  |
| 8                | 113.283215 | 35.063401 | 198  | 491  |
| 9                | 113.302151 | 35.117702 | 175  | 466  |
| 10               | 113.243384 | 35.040751 | 183  | 436  |
| 11               | 113.222355 | 35.01118  | 173  | 453  |
| 12               | 113.218591 | 35.078023 | 181  | 486  |

5.2. Example Solution

Arithmetic parameter setting:
1) Node number = 12
2) For the transportation from the distribution centre to the distribution point, using small Van trucks with standard volume of 8 cubic meters and standard load of 1.5 tons. The actual capacity of the truck is selected as the standard load capacity. Take a single express delivery volume of 11748.04 square centimetres [17]. A truck can carry about 680 express deliveries.
3) According to the ARCGIS geographic information system, the actual distance between the nodes is calculated. The results are shown in Table 2.

Table 2. The actual distance between nodes.

| Actual distance/km | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|--------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1                  | 4.0 | 8.2 | 0.0 | 7.0 | 9.5 | 3.0 | 6.0 | 14.5| 5.5 | 14.5| 15.5| 16.7|
| 2                  | 23.2| 21.8| 29.3| 22.8| 18.7| 16.7| 25.0| 23.0| 23.0| 27.0| 25.9| 27.3|
| 3                  | 0.8 | 29.3| 28.2| 21.3| 21.9| 23.0| 7.2 | 6.5 | 0.0 | 6.3 | 4.4 | 8.0 |
| 4                  | 2.9 | 0.0 | 0.0 | 2.9 | 9.5 | 14.3| 15.1| 21.3| 20.7| 25.0| 25.7| 27.3|
| 5                  | 28.9| 20.7| 28.6| 21.3| 20.4| 19.7| 9.1 | 6.6 | 6.3 | 0.0 | 10.1| 13.9|
| 6                  | 32.7| 25.0| 34.7| 27.9| 26.5| 27.4| 10.7| 10.7| 4.4 | 10.1| 3.8 | 4.7 |
| 7                  | 34.7| 34.3| 27.4| 28.5| 30.8| 9.1 | 3.6 | 8.0 | 0.0 | 3.8 | 0.0 | 7.4 |
| 8                  | 35.3| 34.1| 27.3| 27.7| 28.1| 13.3| 12.3| 6.1 | 8.8 | 4.7 | 7.4 | 0.0 |
| 9                  | 19.0| 16.5| 11.0| 10.0| 9.1 | 9.3 | 7.8 | 14.0| 10.8| 18.3| 21.7| 19.0|

The vehicle routing under the co-distribution mode obtained by the algorithm is shown in Table 3.

Table 3. Running results.

| Vehicle | Route   | Start load | Distance | Total length/km |
|---------|---------|------------|----------|-----------------|
| 1       | 0-8-10-0| 198        | 36.71    |                 |
| 2       | 0-10-12-0| 364       | 42.03    |                 |
| 3       | 0-4-0   | 227        | 19.92    | 283.64          |
| 4       | 0-1-2-0 | 431        | 39.46    |                 |
| 5       | 0-7-6-0 | 308        | 19.96    |                 |
The result of vehicle optimization shows that the total distance of transportation is 283.64 kilometers. Distribution points that need to be split have several important characteristics: close to the distribution centre, high demand for delivery or pick-up, or located in a relatively dense distribution point centre. Distribution points that need to be split are usually at the beginning or end of the route, but not always. Analyzing these points, on the one hand, can make logistics companies pay attention to these distribution points, on the other hand, it enables us to design more effective algorithms.

In order to verify the validity of the joint distribution model, under the same experimental parameters, the traditional distribution model is implemented in Wuzhi County. For the same use of vehicles, the distribution path length is as shown in Table 4.

| Joint distribution model | Traditional distribution model |
|--------------------------|-------------------------------|
| vehicle 1 | 36.71 | 1 | 27.38 |
| vehicle 2 | 42.03 | 2 | 34.92 |
| vehicle 3 | 19.92 | 3 | 29.41 |
| vehicle 4 | 39.46 | 4 | 31.25 |
| vehicle 5 | 19.96 | 5 | 23.31 |
| vehicle 6 | 18.24 | 6 | 49.83 |
| vehicle 7 | 25.16 | 7 | 25.13 |
| vehicle 8 | 43.99 | 8 | 24.49 |
| vehicle 9 | 38.17 | 9 | 38.63 |

The results of table show that the number of vehicles used in joint distribution is equal to that of traditional distribution. The total vehicle routing length of traditional distribution centre is 344.2 km, which exceeds 21% of the common distribution route. Joint distribution mode has advantages for the distribution of rural express logistics.

6. Summary and Prospect
Rural logistics combines physical stores with e-commerce organically, which makes the economy and the Internet produce superposition effect. It is conducive to promoting consumption, promoting the upgrading of agricultural industry and rural development. In order to reduce the cost of rural logistics, this paper firstly analyses the characteristics of rural logistics distribution, introduces the strategy of joint distribution, constructs the SVRPPD mathematical model of rural logistics distribution, and uses competitive decision algorithm to solve the problem according to the characteristics of the model. The experimental results show that the co-distribution strategy is superior to the traditional distribution strategy in overall planning of regional logistics resources from the perspective of global optimization. It can not only effectively reduce the cost of distribution, but also shorten the total driving distance of vehicles.

For the future research, we can consider expanding the scope of research, considering whether the split has advantages under the restriction of access times, and the improvement of the algorithm.

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