Application of split delivery vehicle routing problem in Urban Express Joint Distribution

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Abstract. This paper studies the problem of urban express joint distribution. Considering the problem of distribution complexity of city express delivery due to multiple frequency and small quantity and difficult to form economies of scale, we proposed the joint distribution mode and a mathematical model of split delivery vehicle routing problem based on the mode with the goal of minimum total distribution cost. Then an improved competition decision algorithm based on the characteristics of the model was designed. Finally, the effectiveness and practicability of the model and algorithm were illustrated by calculations.

1. Introduction  
With the rapid development of urban trade, the demand for logistics distribution is becoming higher and higher. Multi-frequency and small-scale distribution mode has become the mainstream, and the single logistics enterprise distribution mode can’t meet the current logistics development status. In order to effectively improve the efficiency and quality of terminal logistics distribution, many large logistics enterprises have begun to optimize terminal logistics distribution. Therefore, based on the integration and sharing of logistics resources, the joint distribution mode of logistics terminals emerges with the goal of reducing the cost of logistics terminal distribution. In modern logistics, transportation is the key link and occupies a large proportion of cost [13]. Reducing the cost of vehicle transportation in the distribution link is a key link to reduce the total cost of joint distribution.

Vehicle routing problem has attracted much attention since it was proposed by Ramser and Datzing in 1959. The VRP problem can be expressed as: having a distribution center and individual customer point, whose location and demand are known, how to make the vehicle have the shortest driving path while meeting the needs of each customer point, and return to starting point. Through the research, it is found that the demand of customer points is split, that is, relaxing the restriction that customer points can only visit once in the traditional vehicle routing problem can reduce the no-load rate of vehicles, shorten the driving distance, and thus reduce the transportation cost. The urban express logistics based on joint distribution mode has the characteristics of huge downstream quantity and relatively small upstream quantity in the actual operation process. Because of the large number of downstream express delivery, how to meet the quantity requirements of downstream express delivery has become the key to solve the problem of urban express logistics distribution. Because of the characteristics of urban express logistics, it is necessary to split the demand of customer points. Therefore, it is of great significance to apply the split delivery vehicle routing problem (SDVRP) to the joint distribution of
urban express logistics.

SDVRP was first proposed by Dror and Trudeau in 1989[1]. Since its development, there have been many extended models. Fu Z [2] proposed the order-based vehicle routing problem with soft time windows. Yong P [3] proposes a demand detachable vehicle path problem with two-dimensional packing constraints. Zhang Dezhi [4] takes into account the impact of different planning routes on driver's income and workload, and proposes a separable vehicle routing problem, which aims at minimizing the route cost and optimizing the route equilibrium. Shi A N [14] proposes a Vehicle Routing Problem with Multiple trips and Multiple Time Windows and Split Delivery that require multi-vehicle multiple delivery situations like dispatching emergency vehicles. Mahdi [5] presents the problem of vehicle routing with limited capacity but unknown customer demand, which can only be known when the vehicle arrives. Marco [6] proposes a vehicle routing problem with a single commodity demand. By studying and summarizing the previous achievements, Wang Qiguang [15] proposed the vehicle routing problem (CSDVRP) with split demand under joint distribution. JIANG ting [7] designed an improved artificial bee colony algorithm to solve the SDVRP problem. Zhong-Jun H [8] improves the traditional genetic algorithm to solve by combining the strong global search ability of genetic algorithm with the local search ability of simulated annealing. Zhai Jianing [9] uses a three-stage algorithm of pre-clustering path to solve the problem of demand-separable vehicle routing. DR Gaur [10] solves vehicle routing problem with split demand by improved approximation algorithm. J Shi [11] by combining local search to improve the particle swarm optimization algorithm, to solve such problems.

In this paper, we will change the traditional distribution mode, establish a joint distribution alliance with cooperation of several express enterprises, and apply the vehicle routing problem with split delivery demand to the joint distribution mode, establish a mathematical model with the minimum total distribution cost as the goal, and design an improved decision-making competition algorithm according to the characteristics of the model. Finally, an example is given to demonstrate the effectiveness and practicability of the model and algorithm.

2. Mathematical Model

2.1 Problem description

The problem of the vehicle path with the detachable transmission requirement under the common distribution can be represented by the undirected graph $G = (N, E)$: where the set of points is $N = \{0, 1, 2, ..., n\}$, 0 is the distribution center, and the rest are customer points; E is the set of edges in the undirected graph, $E = \{(i,j), i\neq j\}$.

In order to ensure that the model is applicable to this paper, while not losing its generality, the following assumptions need to be made by multiple models:

1. The capacity of distribution centers can meet the needs of customer centers;
2. The demand of customer points does not exceed the capacity of distribution vehicles;
3. The driving distance of the vehicle does not exceed the maximum distance and the vehicle run in a stable state.

2.2 Symbols and Variables

Symbol: $Q_k$ represents the loading capacity of the No. K vehicle; $d_i$ represents the corresponding demand of customer point i, $d_0 = 0$; $K$ represents the total number of vehicles used in all routes ; $S$ is a set of all customer points except the parking lot; $c_{ij}$ represents the distance or transportation cost of vehicles directly arriving at customer point j from customer point i; and $y_{ik}$ represents the actual load.
of the No. K car at the customer point i and the demand at that point $0 \leq y_{ik} \leq 1$.

Decision variables: $X_{ij}^k$ represents that if the vehicle passes by the side (i, j) of 1, otherwise it is 0.

2.3. SDVRP Model Based on Joint Distribution Strategy
This paper establishes a model of vehicle routing problem with detachable transmission requirements for common distribution with the goal of minimum total distribution cost.

$$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{K} c_{ij}^k x_{ij}^k$$  \hspace{1cm} (1)

s. t. \hspace{1cm} \sum_{k=1}^{K} \sum_{j=0}^{n} x_{ij}^k \geq 1 \hspace{1cm} (j = 0,1,...,n) \hspace{1cm} (2)

\hspace{1cm} \sum_{i=0}^{n} x_{ij}^p = \sum_{j=0}^{n} x_{ji}^p \hspace{1cm} (p = 0,1,...,n; k = 1,2,...,K) \hspace{1cm} (3)

\hspace{1cm} \sum_{k=1}^{K} y_{ik} = 1 \hspace{1cm} (i = 1,2,...,n); \hspace{1cm} (4)

\hspace{1cm} \sum_{i=0}^{n} d_{ij} y_{ik} \leq Q_k \hspace{1cm} (k = 1,2,...,K) \hspace{1cm} (5)

\hspace{1cm} x_{ij}^k = 0,1 \hspace{1cm} (i = 0,1,...,n; j = 0,1,...,n; k = 1,2,...,K) \hspace{1cm} (6)

Formula (1) is the objective function, It is the shortest driving path of a vehicle. Formula (2) is used to ensure that each customer point is visited at least once. Formula (3) denotes that any vehicle visits a point and leaves it at the same time. The constraint shown in Formula (4) is that all requirements of the customer point are met. Formula (5) indicates that the actual load of a vehicle does not exceed the capacity of the vehicle. The condition shown in Formula (6) is that if the vehicle K passes through the edge (i, j), the value is 1, otherwise it is 0.

3. Competitive Decision Algorithm
SDVRP is a NP-hard problem. Precise algorithms are difficult to apply to such problems. Heuristic algorithms have strong applicability to such problems. In this paper, the competitive decision algorithm of heuristic algorithm is used to solve SDVRP. Competitive decision algorithm (CDA) is an optimization algorithm based on the analysis of various competition mechanisms and decision-making principles produced by human society, and the characteristics of competition producing optimization and decision-making results [12].

In order to eliminate some contingencies in the process of the algorithm, this paper will make $m$-round competition ($m$ is the product of the number of initial states, the number of competitiveness functions and the number of decision functions) to obtain the optimal results. The flow of the algorithm is shown below.

Step 1: Initial layout
The competitiveness function represented by cc_count is 1, and the decision function represented by dd_count is 1.

Step 2: competitive force function
The competitive force function in this problem is the distance between customer h and customer n, which assigns demand to vehicle i, expressed by $y_{ik}$.

Step 3: Decision function
If customer h assigns the demand to vehicle i, but there is another vehicle ii, which satisfies $(ii, j) < (i, j)$, and vehicle II can fulfill customer h's demand, in this case customer h can be assigned to vehicle II.
ii. If no vehicle can steal resources from other vehicles, the equilibrium state is reached at this time.

Step 4: Eliminate redundant or inappropriate resources

In the equilibrium state, if customer h allocates demand to vehicles I and j, and there is \((i, h) > (j, h)\) at this time, and there is no competition for resources at this time, then the inappropriate resources of vehicle J need to be cleared at this time.

Step 5: Resource Exchange

Check if there are vehicles that need to be forcibly exchanged for shorter distances, if it exists, it will be intersected.

4. Model application analysis

This paper selects Jiaozuo urban city express logistics as a case for model application analysis, divided into three parts to complete. The first is the selection of the common distribution site, the second is the determination of the demand, and the third is the distribution route of Jiaozuo urban city express logistics through the calculation of the model and data.

4.1 Determination of the joint distribution site of Jiaozuo urban city express logistics

In order to make full use of existing resources and save construction funds and land, the first-level distribution center in this paper selects from existing facilities that are currently operating. Based on the convenience of internal and external transportation and the feasibility of implementation, this paper selects Taihang Logistics Park as the first-level distribution center of Jiaozuo City. It is located at the intersection of Taihang Road and Taihang West Road in Jiefang District of Jiaozuo City. The latitude and longitude coordinates are (113.202688, 35.254272).

According to the data provided by the Jiaozuo municipal people's government, by the end of 2018, the total area of Jiaozuo urban area was 295.4 square kilometers. According to the central theory, the number of secondary stations planned by Jiaozuo city is 12.

In this paper, k-means clustering algorithm combined with the theory of center earth and manual coordinate search method is selected to solve the location problem of secondary distribution center in Jiaozuo city.

Jiaozuo city on the record of the three-level site a total of about 114. Now it is necessary to integrate all three-level sites, 12 secondary distribution centers are set up reasonably in all districts of the city, so that the distribution coverage to each three-level site, this paper USES the distribution distance as the main reference standard.

After investigation, the location distribution of 114 express three-level distribution stations in Jiaozuo City was obtained, and the latitude and longitude coordinates of each station were obtained by means of the map coordinate picker. Using the K-means clustering algorithm program solve the location of each secondary site and the covered three-level site.

The K-means clustering algorithm program is used to iteratively update the location of the distribution center, and the optimal layout scheme is obtained by iterating four times: the geographic coordinates of the 12 secondary distribution centers are distributed from left to right and top to bottom.

| Secondary site | Latitude and longitude coordinates | Service level three site |
|----------------|-----------------------------------|--------------------------|
| 1              | (113.175721, 35.243052)          | 9, 23, 46, 54, 57, 71, 89, 90, 91, 92 |
| 2              | (113.199944, 35.195825)          | 20, 24, 50, 51, 52, 66, 67 |
| 3              | (113.2111, 35.241184)            | 14, 16, 26, 29, 39, 43, 45, 61, 64, 83, 84 |
| 4              | (113.228507, 35.262792)          | 13, 22, 35, 36, 42, 49, 63, 81, 85, 86, 87, 88 |
| 5              | (113.236871, 35.237524)          | 2, 11, 17, 30, 33, 40, 47, 70, 76 |
| 6              | (113.233253, 35.203755)          | 3, 19, 27, 28, 37, 44, 53, 59, 68, 69, 79, 104, 112 |
| 7              | (113.2576, 35.258626)            | 7, 77, 97, 98, 99, 100 |
4.2 Delivery quantity of each site

According to the statistics of Jiaozuo postal administration bureau, in 2018, the number of small express items in Jiaozuo was about 7.7795 million, and the average number of express items needed to be handled by each third-level station every day was: 7779500/365/114=187. In this paper, according to the community population density of the three level sites in the area, according to experience appropriate increase or decrease site business volume, in order to determine the number of parcels each three level sites need to deal with. At the same time control the secondary site daily business total number of three sites covered by 187 ups and downs, from the above known each secondary site to serve three sites. If each cluster center is regarded as a distribution center, then the demand of secondary distribution center is the total demand of all three-level stations within the service scope. The demand is shown in the figure below.

| Secondary site | 1 demand | 2 demand | 3 demand | 4 demand | 5 demand | 6 demand | 7 demand |
|----------------|----------|----------|----------|----------|----------|----------|----------|
| 8 (113.257859, 35.231614) | 5,8,15,38,58,78,93,94,95 | 1,34,41,62,80,108,111,113 | 10,21,25,32,48,55,60,73,74,75,102 | 4,6,18,31,56,65,101,109,110,114 |
| 9 (113.264906,35.172334) | 5,8,15,38,58,78,93,94,95 | 1,34,41,62,80,108,111,113 | 10,21,25,32,48,55,60,73,74,75,102 | 4,6,18,31,56,65,101,109,110,114 |
| 10 (113.31571,35.25749) | 5,8,15,38,58,78,93,94,95 | 1,34,41,62,80,108,111,113 | 10,21,25,32,48,55,60,73,74,75,102 | 4,6,18,31,56,65,101,109,110,114 |
| 11 (113.287807,35.207795) | 5,8,15,38,58,78,93,94,95 | 1,34,41,62,80,108,111,113 | 10,21,25,32,48,55,60,73,74,75,102 | 4,6,18,31,56,65,101,109,110,114 |
| 12 (113.378208,35.305527) | 5,8,15,38,58,78,93,94,95 | 1,34,41,62,80,108,111,113 | 10,21,25,32,48,55,60,73,74,75,102 | 4,6,18,31,56,65,101,109,110,114 |

4.3 path solving

From the above, the demand and location of each secondary site are known, and the distance between each secondary site and between the distribution center and the secondary site is now given.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|----|----|----|
| 1 | 0  | 5.69 | 3.21 | 5.27 | 5.59 | 6.81 | 7.63 | 7.57 | 11.29 | 12.81 | 10.91 | 19.65 |
| 2 | 5.69 | 0  | 5.14 | 7.88 | 5.72 | 3.15 | 8.72 | 6.6 | 6.46 | 12.55 | 8.09 | 20.27 |
| 3 | 3.21 | 5.14 | 0  | 2.88 | 2.38 | 4.63 | 4.65 | 4.39 | 9.09 | 9.68 | 7.9 | 16.78 |
| 4 | 5.27 | 7.88 | 2.88 | 0  | 2.91 | 6.58 | 2.68 | 4.37 | 10.59 | 7.94 | 8.15 | 14.4 |
| 5 | 5.59 | 5.72 | 2.38 | 2.91 | 0  | 3.77 | 3.01 | 2.02 | 7.68 | 7.5 | 5.69 | 14.89 |
| 6 | 6.81 | 3.15 | 4.63 | 6.58 | 3.77 | 0  | 6.49 | 3.82 | 4.53 | 9.58 | 4.98 | 19.36 |
| 7 | 7.63 | 8.72 | 4.65 | 2.68 | 3.01 | 6.49 | 0  | 3 | 9.62 | 5.28 | 6.28 | 12.13 |
| 8 | 7.57 | 6.6 | 4.39 | 4.37 | 2.02 | 3.82 | 3 | 0 | 6.62 | 5.99 | 3.8 | 13.67 |
| 9 | 11.29 | 6.46 | 9.09 | 10.59 | 7.68 | 4.53 | 9.62 | 6.62 | 0  | 10.53 | 4.46 | 18.03 |
| 10 | 12.81 | 12.55 | 9.68 | 7.94 | 7.5 | 9.58 | 5.28 | 5.99 | 10.53 | 0  | 6.08 | 7.79 |
| 11 | 10.91 | 8.09 | 7.9 | 8.15 | 5.69 | 4.98 | 6.28 | 3.8 | 4.46 | 6.08 | 0  | 13.62 |
| 12 | 19.65 | 20.27 | 16.78 | 14.4 | 14.89 | 19.36 | 12.13 | 13.67 | 18.03 | 7.79 | 13.62 | 0  |
| 0 | 2.76 | 6.5 | 1.64 | 2.53 | 3.62 | 6.27 | 5.01 | 5.61 | 10.72 | 10.27 | 9.3 | 16.92 |

4.4 Result analysis

The optimal results obtained by the operation are shown in Table 4-4.1 below.
Table 4. Vehicle optimal path result.

| Vehicle number | Travel distance/km | Driving path         | Total distance traveled/km |
|----------------|-------------------|----------------------|----------------------------|
| 1              | 38.71             | 0-7-8-10-12-0        |                            |
| 2              | 24.48             | 0-11-9-0             | 114.66                     |
| 3              | 15.92             | 0-6-0                |                            |
| 4              | 15.73             | 0-5-8-6-0            |                            |
| 5              | 12.21             | 0-3-4-7-0            |                            |
| 6              | 7.61              | 0-3-1-0              |                            |

When the Jiaozuo urban area is independently distributed by the competition decision algorithm, the above steps are also performed. The result shows that the number of vehicles required is 8 and the total driving path of the vehicle is 132.65 kilometers. The comparison results show that the common distribution can save 25% of the vehicle, and the total driving path can be shortened by 14%. Through the above data, it can be found that the implementation of common distribution can significantly reduce the cost of Jiaozuo city express logistics, and the development of economic and trade in the city is positive.

5. Conclusion
This paper proposes a common distribution mode for cooperation among a number of express delivery companies. At the same time, the problem of vehicle routing with detachable requirements is applied to this model, a mathematical model is established, and a competitive decision algorithm is used to solve the problem. Finally, verify the validity of the model and examples by comparing with the independent distribution model. The next step in the research direction can be to consider the application of a variety of different algorithms to split delivery vehicle routing problem in the common distribution mode.

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