Optimization of Campus Terminal Distribution in the Mode of "Self-Service Cabinet + Unmanned Vehicle"

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Abstract—Campus end delivery is an important link to deliver express delivery from campus delivery center to demand point, and choosing suitable delivery mode and delivery path is an important way to improve delivery efficiency and reduce logistics cost. Taking the campus delivery center of Beijing Wuzi University as an example, the problem of choosing the campus terminal delivery mode and joint optimization of the delivery path under the mode of "self-service cabinet + unmanned vehicle" is studied. In view of the problems in the operation of the "self-service cabinet + unmanned vehicle" mode, the joint optimization problem of delivery mode selection and unmanned vehicle path under the "self-service cabinet + unmanned vehicle" scenario is proposed, and a mathematical model is established and a two-stage algorithm is designed to solve the problem. Finally, a simulation example is generated using the basic data of JD Express in the campus distribution center of Beijing Wuzi University. The research results provide a theoretical basis and a reference for decision making to solve the problem of campus end delivery mode selection and route optimization under the mode of "self-service cabinet + unmanned vehicle".

Keywords—*Campus End Delivery; Self-Service Cabinet + Unmanned Vehicle; Delivery Mode Selection; Delivery Path Optimization; Greedy Algorithm*

I. INTRODUCTION

In recent years, with the popularity of the Internet and the rise of online shopping, the order volume and business volume of the logistics industry has been growing, and the timeliness of end delivery has become more and more demanding. The ability to deliver goods to customers in a timely manner is the main basis for customers' evaluation of logistics delivery satisfaction[2][3]. The Campus Express Industry Development Report (2019) shows that college students are an important group of online consumption, and the number of express parcels on university campuses has increased year by year in recent years, and universities have established their own campus terminal distribution centers[1]. Beijing Wuzi University covers an area of more than 600 acres, and the express delivery center was established in 2013, covering the whole campus. The distribution center has gone through the following stages since its establishment: manual mode, self-service cabinet mode, and "self-service cabinet + unmanned vehicle" mode (as shown in 0).

The "self-service cabinet + unmanned vehicle" model [4][5] is based on the self-service cabinet model with the addition of unmanned vehicle delivery service, which can provide diversified services for customers and meet the flexibility of customer pick-up time as well as the demand for home delivery. At present, campus staff mainly rely on their experience to arrange the delivery mode of each parcel, with little consideration to the characteristics of the parcel and the actual customer needs. Due to the lack of experience of the staff, there are often situations where the self-pickup cabinets are full and the unmanned vehicles have a low fill rate or wait in the distribution center, indicating that the delivery mode of the parcels is unreasonable [6]. In the process of transportation, due to the unreasonable distribution path planning, the delivery distance is often far, the delivery time is long, and the delivery cost is high [4]. Therefore, in the operation of the "self-service cabinet + unmanned vehicle" mode, the selection of the distribution mode of parcels and the path planning of the unmanned vehicle are the key factors affecting the operation efficiency of the "self-service cabinet + unmanned vehicle" mode.

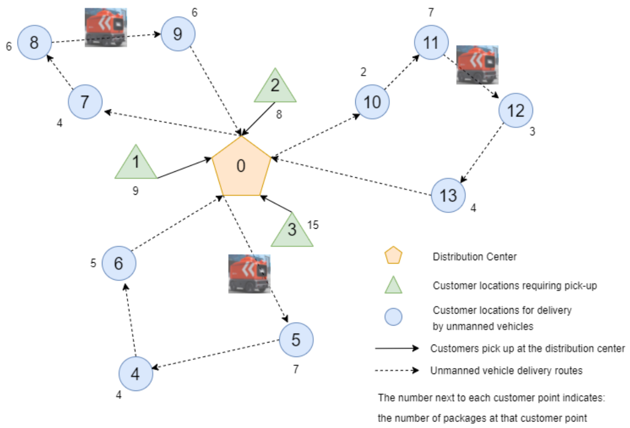

Fig 1: "self-service cabinet + unmanned vehicle" mode

Since the "self-service cabinet + unmanned vehicle" mode is a new express terminal delivery mode, there is a lack of theoretical research results in the existing literature and a lack of decision-making basis for courier managers in actual operation [7]. In order to improve the delivery efficiency and reduce the delivery cost, this paper intends to carry out theoretical and application research on the "self-service cabinet + unmanned vehicle" mode in combination with the delivery scenario of the "self-service cabinet + unmanned vehicle" mode in the campus courier center of Beijing Wuzi University. The paper focuses on the selection of the delivery mode of express parcels and the planning of the unmanned vehicle delivery path, so as to help the campus courier center formulate the optimal delivery strategy, improve the delivery efficiency and reduce the total cost of delivery.

II. PROBLEM DESCRIPTION AND MODEL CONSTRUCTION

A. *Problem description*

The distribution center receives n parcels in a period of time, and the location of the demand point of each parcel is known. The distribution center has Q pick-up cabinets and one unmanned vehicle, and the unmanned vehicle can deliver P parcels in one trip. The distance from the distribution center to each demand point, the unit distance cost of each customer, and the fixed cost of one delivery by the unmanned vehicle are known. Assume that the unmanned vehicle can deliver at most m trips per day, determine the delivery mode for each parcel, and for the parcels delivered by the unmanned vehicle, plan the parcels for each delivery trip and the driving path for the unmanned vehicle. The sum of the customer's self-pickup cost, the path cost of the unmanned vehicle and the fixed cost of using the unmanned vehicle is minimized.

To simplify the problem, the pickup time of customers when they go to the pickup point to pick up their parcels and the pickup time of customers when the unmanned vehicle delivers the parcels to the demand point are not considered. Only the fixed cost of each delivery trip of the unmanned vehicle and the cost of the customer's round trip time to the pickup counter are considered. Assume that the location of the distribution center is 0, while the parcels between different trips of unmanned vehicles cannot be swapped. It is necessary to consider constraints such as the capacity limit of unmanned vehicles and the capacity limit of self-pickup cabinets. The delivery mode of each parcel and the driving path of the unmanned vehicle for each trip are determined with the objective of minimizing the sum of the customer's self-pickup cost, the path cost of the unmanned vehicle and the fixed usage cost of the unmanned vehicle..

B. Model parameters

$K=\{0,1,2,\cdots,m\}$ — denotes the set of delivery modes k, 0 denotes self-pickup, $1\cdots m$ denotes unmanned vehicle delivery, where each value corresponds to one trip.

$K^*=\{1,2,\cdots,m\}$ — denotes the set of unmanned vehicle delivery modes, and $1\cdots m$ denotes unmanned vehicle delivery, where each value corresponds to one trip.

$N^k=\{1,2,\cdots,|n^k|,|n^k|+1\}$ —The set of nodes for the kth delivery by the unmanned vehicle. $|n^k|$ denotes the number of nodes on the kth delivery path, and node 1 and $|n^k|+1$ denote the distribution centers, $k\in K^*$.

$N=\{1,2,\cdots,n\}$ — denotes the set of customer packages l, $l\in N$.

G —Indicates the fixed usage cost of one delivery by an unmanned vehicle.

P —Indicates the capacity of the unmanned vehicle.

Q —Indicates the capacity of the self-service cabinet.

s —Indicates the cost per unit distance yuan(meter) for customers to pick up at the pick-up point.

c —denotes the unit distance cost of unmanned vehicle delivery yuan(meter).

d_l —Indicates the distance (in meters) from the location of the customer's package l to the distribution center.

d_{ij}^k —denotes the distance between demand points i and j on the distribution route when the kth delivery is made by an unmanned vehicle, $k\in K^*$

C. Decision variables

x_{lk} —Indicates whether the l th parcel is delivered by the first mode, 1 if the l th parcel is delivered by the kth mode, 0 otherwise, $k\in K$.

y_k —Indicates whether the kth distribution mode is used, 1 if it is used, 0 otherwise, $k\in K$.

z_{ij}^k —denotes whether the unmanned vehicle travels from node i to node j on the kth delivery route, $k\in K^*$.

u_i^k — denotes the delivery order of node i on the kth delivery route for the unmanned vehicle (as a positive integer), $k\in K^*$.

D. Mathematical model

The mathematical model of the 'self-pickup + unmanned vehicle' delivery model is established as follows :

$$Min \sum_{l\in N} 2\times d_l\times s\times x_{l0}+\sum_{k\in K^*} G\times y_k +\sum_{k\in K^*}\sum_{i\in N^k}\sum_{j\in N^k,i\neq j} d_{ij}^k\times z_{ij}^k\times c \quad (1)$$

The constraints are:

$$\sum_{k\in K} x_{lk}=1,\forall l\in N \quad (2)$$

$$\sum_{l\in N} x_{l0}\le Q \quad (3)$$

$$\sum_{l\in N} x_{lk}\le P,\forall k\in K^* \quad (4)$$

$$x_{lk}\le y_k,\forall l\in N,k\in K \quad (5)$$

$$\sum_{i\in N^k} z_{ij}^k=1,\forall k\in K^*,j\in N^k/\{1\},i\neq j \quad (6)$$

$$\sum_{j\in N^k,i\neq j} z_{ij}^k=1,\forall k\in K^*,i\in N^k/\{|n^k|+1\} \quad (7)$$

$$u_j^k\ge u_i^k+(|n^k|+1)(z_{ij}^k-1)+1,\forall i\in N^k, j\in N^k,i\neq j,k\in K^* \quad (8)$$

$$u_1^k=0,u_{|n^k|+1}=|n^k|,\forall |n^k|\in N^k,k\in K^* \quad (9)$$

$$z_{ij}^k\in\{0,1\},u_i^k\ge 0,\forall i\in N^k,k\in K^* \quad (10)$$

$$x_{lk}=\{0,1\},\forall l\in N,k\in K \quad (11)$$

$$y_k=\{0,1\},\forall k\in K \quad (12)$$

In the above model, equation (1) is the objective function that minimizes the self-pickup cost of the customer to pick up the parcel from the self-pickup cabinet, the fixed distribution cost of the unmanned vehicle and the path travel cost of the unmanned vehicle; equation (2) indicates that a parcel can only choose one distribution mode; equation (3) is the capacity limitation constraint of the self-pickup cabinet, indicating that the total number of parcels chosen for self-pickup is less than the capacity of the self-pickup cabinet; equation (4) is the capacity limitation constraint of the unmanned vehicle, indicating that the total number of parcels distributed by the unmanned vehicle cannot exceed the number of parcels that the unmanned vehicle can accommodate. Equation (5) indicates that the l th parcel can be delivered by the k th mode only when the k th mode is selected. Equation (6) ensures that at any one delivery path, except for any point j of node 0, only one predecessor node i forms a path with it. Equation (7) ensures that in any distribution path, except for any point i at node $|n^k|+1$, there is only one posterior node j with which it forms a path. Equation (8) avoids the appearance of sub-loops on any distribution path. Equation (9) ensures that on any one distribution path k, the value of u_i^k is the sequence value of node i on that path. Equations (10)-(12) are the constraints on the values of the decision variables.

III. SOLUTION METHOD

The model established in this paper is an NP-Hard problem, so a two-stage algorithm is designed to solve the model. In the first stage, a greedy algorithm is used to solve the problem of selecting the delivery method of parcels in the mode of "self-service cabinet + unmanned vehicle"; in the second stage, a scanning algorithm is used to plan the delivery path of the unmanned vehicle for the parcels delivered by the unmanned vehicle calculated in the first stage.:

A. Stage 1: Pattern Selection - Greedy Algorithm

Since the path cost of the unmanned vehicle is not considered, the parcels can be sorted from largest to smallest according to the self-pickup cost of each parcel, the parcels are grouped according to the capacity of the unmanned vehicle, and the relationship between the total self-pickup cost of each group and the fixed cost of the unmanned vehicle is used to determine whether this group of parcels is delivered by the unmanned vehicle.

B. Stage 2: Path Planning-Scanning Algorithm

By solving the first stage of the problem, the delivery mode of each parcel can be determined. The parcels delivered by each unmanned vehicle and the coordinates of the corresponding customer demand point location are known. Since the distribution cost of each unmanned vehicle trip is composed of two parts: vehicle fixed usage cost and vehicle driving cost, and both vehicle fixed usage cost and vehicle unit driving cost are fixed. Therefore, in this stage, the optimization objective can be transformed into planning the delivery path of unmanned vehicles with the shortest delivery distance per trip. The location coordinates of the customer point where the parcel is located are represented on a map. Then, the scanning algorithm is used to scan with the unmanned vehicle capacity as the limiting constraint to assign the parcels that need to be delivered for each trip to the unmanned vehicle, and thus plan the driving path of the unmanned vehicle for each trip.

IV. EXPERIMENT

This paper takes the historical business data of the Beijing Wuzi University JD Express Center as the research data, writes a two-stage algorithm implementation program in Python and solves the model to optimize the parcel distribution scheme. The computer configuration used for this experiment is 2 GHz CPU, 8 GBRAM, and 64-bit operating system.

A. Example data

The Beijing Wuzi University JD Express Center needs to deliver about 200-400 express parcels every day, and these parcels are transported to the campus distribution center by JD Express delivery vehicles in 3-4 batches, and the number of parcels delivered each time is about 80-100.

TABLE I. PACKAGES – DEMAND POINT

Package ID	Demand Point Number	Package ID	Demand Point Number
1-8	1	46-52	7
9-18	2	53-62	8
19-21	3	63-70	9
22-29	4	71-78	10
30-34	5	79-80	11
35-45	6		

Take the 80 pieces of parcels delivered by the JD Express delivery vehicle on a certain day as an example, the construction arithmetic example. The capacity P of the unmanned vehicle in the campus distribution center is 16 pieces. According to the limitations of charging time, range and daily working time of the unmanned vehicle, it is estimated that for each batch of 80 parcels, the unmanned vehicle can deliver at most 4 trips. The number Q of parcels that can be put into the self-service cabinet for each batch cannot exceed 50 pieces at most.

Since the parcel recipients in the campus distribution center are mainly students and staff, the demand points of parcels are simplified to 11 according to the locations of student dormitories and office buildings, the latitude and longitude coordinates of each location are obtained according to the campus map, and the distance between any two demand points is calculated, and the total round-trip time for customers to pick up their parcels from the distribution center. Let the cost of customer pickup at the pickup point be proportional to the round-trip distance, the unit distance cost s is 0.001 yuan(meter), the fixed cost of unmanned vehicle per delivery trip is 10 yuan, and the unit driving cost c of unmanned vehicle is 1 yuan(km) (mainly the cost of consumed electricity).

The demand point information corresponding to 80 express parcels is shown in TABLE I. . The coordinates of the demand point location on campus are shown in TABLE II. .

TABLE II. DEMAND POINT LOCATION COORDINATES

Demand Point Number	Longitude	Latitude	Demand Point Number	Longitude	Latitude
0	116.646945	39.937789	6	116.642606	39.939248
1	116.643774	39.938519	7	116.643594	39.936247
2	116.642741	39.93847	8	116.64465	39.936721
3	116.642624	39.938878	9	116.64597	39.935396
4	116.643693	39.938913	10	116.646006	39.935787
5	116.643612	39.939314	11	116.645903	39.936185

B. Simulation

According to the above data, the model is solved by using the two-stage algorithm designed in this paper. The results of the first stage are shown in TABLE III. .

TABLE III. ALGORITHM PHASE 1 --DETERMINE THE PARCEL DELIVERY MODEL

Delivery mode	Package ID
Self-pickup	46、47、48、49、50、51、52、53、54、55、56、57、58、59、60、61、62、63、64、65、66、67、68、69、70、71、72、73、74、75、79、80
Unmanned vehicles	First time: 1、2、3、4、5、7、8、9、10、11、12、13、14、15、16、30 Second time: 6、17、18、19、20、21、22、23、24、25、26、27、28、29、30、31、78 Third time: 32、33、34、35、36、37、38、39、40、41、42、43、44、45、76、77

In the second stage, the results of unmanned vehicle distribution path and parcel information are shown in TABLE IV. , and the final "self-pickup cabinet + unmanned vehicle" parcel distribution scheme is shown in TABLE IV. based on the algorithm of this paper.

TABLE IV. ALGORITHM PHASE 2-- UNMANNED VEHICLE DELIVERY PATH AND DELIVERY PACKAGE INFORMATION

Unmanned vehicle delivery trips	Path Nodes	Delivery Parcel ID
First time 0→5→6→0	5	30-34
	6	35-45
Second time 0→1→3→4→0	1	1-5
	3	19-21
	4	6-8
Third time	10	71-78

0→10→1→2→0	1	6-8
	2	9-18
Number of unmanned vehicle deliveries: 3 times		
Total cost of "self-service container + unmanned vehicle delivery": 50.34 yuan		

Eventually, the effect of the self-pickup + unmanned vehicle delivery scheme is shown in 0. From the 0, we can clearly see the effect of the whole distribution program.

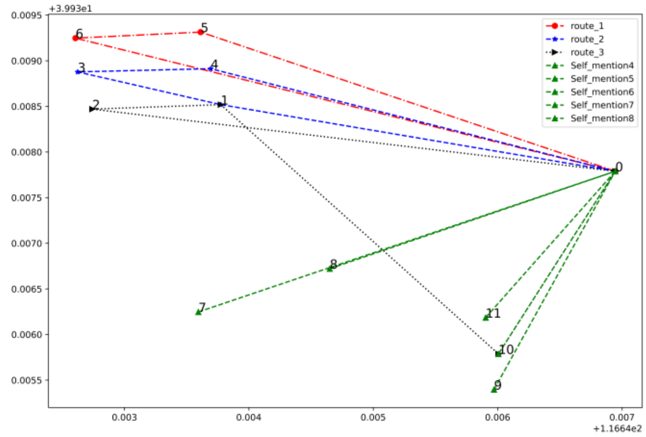

Fig 2: "Self Pickup Cabinet + Unmanned Vehicle" Parcel Delivery Plan

CONCLUSION

The last-mile delivery problem in logistics and distribution scenarios is a complex and challenging problem. The algorithm designed in this paper can provide a solution for this scenario. The algorithm is based on the conditions containing self-pickup containers and unmanned vehicle delivery, and achieves a fast formation of the delivery scheme by optimizing the delivery route and delivery method. It can help logistics companies reduce costs, improve efficiency and enhance customer satisfaction. The algorithm has high practical value and wide application prospects in scenarios containing self-pickup cabinets and unmanned vehicle delivery.

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