Optimization of the delivery route for community group-purchasing fresh products considering customer satisfaction

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Abstract. For this paper, the VRP model on the total cost minimization of fixed cost, transportation cost and penalty cost is developed under the constraint of the delivery time satisfaction function for the characteristics of community group purchasing. On the genetic algorithm optimization, an elite retention mechanism is added, a partial crossover rule is used to design the crossover operator, and the examples are tested. The results show that solving the total cost function can effectively reduce the cost, and the improved genetic algorithm has good computational speed and convergence. At the same time, good satisfaction was obtained, indicating that the company cannot neglect the customer satisfaction experience while pursuing the minimum total cost, which provides a decision reference for achieving the balance between the two.

1. Introduction
Community group buying is a kind of collective consumption mode for people living in the community, as well as a small-scale, collective and localized group buying form. The process is as follows: the head of the community issues various promotional activities to the community residents through WeChat group. After the residents place an order for purchase, the platform enterprise prepares goods and delivers them to the designated community in a timely manner.

The core is the requirement of distribution timeliness, and the timeliness of distribution also directly reflects the satisfaction experience of community residents. Previously, there were few researches on community group-buying, which were generally researches on the development strategy and business model of community group-buying. Community group buying usually arranges delivery according to their own will, which is not scientific but increases the cost of delivery. Near neighbor distribution method, the distribution center after receiving the order, according to the distribution order from the distribution center in turn. Vehicle routing problem (VRPTW) with time window is one of them [1-2]. The mathematical model of transportation under the constraints of time window and vehicle path is studied. Considering the property of NP hard, many researchers adopt meta-heuristic algorithm to solve the problem [3-6]. From another point of view, many researchers have also done a lot of research on the time satisfaction path problem and put forward the frozen logistics transport path model under the condition of satisfying the constraints [7]. Introduced a fuzzy membership function to reflect customer satisfaction with the time window, established a multi-objective optimization model [8]. Analysed the VRP problem with multiple soft time Windows and designed an adaptive tabu search algorithm to solve
it [9]. Constructed a comprehensive customer satisfaction on time window and food freshness, and solved the problem by combining single parent genetic algorithm and ant colony algorithm [10].

On this basis, this paper establishes a multi-constraint objective function model with time, fixed vehicle cost, transportation cost and penalty cost. Finally, a genetic algorithm with 2-OPT optimization is designed.

2. Distribution modest construction considering customer satisfaction

2.1 Question assumptions

Suppose you are in a community enterprise warehouse center, and all the transportation vehicles start from the warehouse center, pass the midway transportation, know the location of the community leader point, arrive at the community leader point for unloading within the specified time window, and all vehicles serve for a number of community leader points. How to reasonably arrange the distribution of vehicles, plan the route, maximize the degree of customer satisfaction to achieve the optimal objective function. The research of this paper is to stipulate the following contents under the condition of maximum customer satisfaction:

- Fixed location of the distribution center and only one, uniformity in the type of vehicle to be delivered, with the same payload.
- The sum of customer demand does not exceed the vehicle’s allotted capacity limit.
- The speed of the delivery vehicle is constant, and the traffic road is clear.
- Each cell has and can only be serviced once, given the cell location, order volume, and arrival time.
- Distribution vehicles start from the distribution center, arrive at the community for unloading, and return to the distribution center after the completion of distribution.
- Transport vehicles must arrive within the specified time of arrival, or they will be punished.

2.2 Symbolism

N is the set of cell points; K is the set of transport vehicles; Q is the maximum load of the vehicle; V is the average driving speed of the transport vehicle; \(d_{ij}\) is the distance between cell \(i\) and cell \(j\); \(p_c\) is the fixed consumption cost of each ca; \(p_r\) is the driving cost of the vehicle per kilometer; \(\epsilon_1\) and \(\epsilon_2\) are the cost per unit of time of waiting and late arrival of the vehicle. Decision variables:

\[
x_{ijk} = \begin{cases} 1, & \text{Vehicle } k \text{ from } i \text{ to } j \\ 0, & \text{Otherwise} \end{cases} \quad i = 0,1, ..., N; j = 0,1, ..., N; k = 1,2, ..., K
\]

\[
y_{ik} = \begin{cases} 1, & \text{Customer } i \text{ is transported by vehicle } k \\ 0, & \text{Otherwise} \end{cases} \quad i = 0,1, ..., N; k = 1,2, ..., K
\]

2.3 Satisfaction fiction

In this paper, the linear continuous time under the vehicle service time window is taken as the customer satisfaction \(CT_i\). The construction customer satisfaction is a linear function, as shown in figure 1. \(CT_i\) is customer satisfaction function, and \(t_i\) is the time when the transport vehicle arrives at customer \(i\).
When the delivery vehicle arrives within the time window expected by the customer \([e_i, l_i]\), the customer satisfaction is 1; When delivery vehicles arrive within \([E_i, e_i]\) and \((l_i, L_i]\), customer satisfaction will decrease linearly with time. When the delivery vehicle is outside the maximum acceptance time range \([E_i, L_i]\), customer satisfaction is 0. The satisfaction function \(CT_i\).

\[
CT_i(t_i) = \begin{cases} 
0, & t_i \notin [E_i, L_i] \\
e_i - E_i, & t_i \in [E_i, e_i] \\
\frac{L_i - l_i}{L_i - l_i}, & t_i \in (l_i, L_i] \\
1, & t_i \in [e_i, l_i] 
\end{cases}
\]  

(1)

2.4 Cost analysis

2.4.1. Fixed costs. The change of fixed cost is only related to the number of vehicles actually involved in distribution. Its function is defined as \(Z_1\), and the expression is

\[
Z_1 = \sum_{k=1}^{K} \sum_{j=1}^{N} x_{0,jk} p_c 
\]  

(2)

2.4.2. Transportation cost. This kind of cost is mainly reflected in fuel consumption, which is proportional to the mileage of distribution vehicles. Its function is defined as \(Z_2\), and the expression is

\[
Z_2 = \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} d_{ij} x_{ijk} p_r 
\]  

(3)

2.4.3 Penalty costs. Failure to deliver within the expected time will result in negative customer satisfaction evaluation. That is, the penalty cost is caused, and its function is defined as \(Z_3\), and the expression is

\[
Z_3 = \varepsilon_1 \sum_{i=1}^{N} \max\{E_i - t_i, 0\} + \varepsilon_2 \sum_{i=1}^{N} \max\{t_i - L_i, 0\} 
\]  

(4)

2.5 Mathematical model construction

Based on the above analysis, it can be concluded that the distribution model under the consideration of customer satisfaction is as below

\[
\text{Max} \frac{1}{N} \sum_{i=1}^{N} CT_i(t_i) 
\]  

(5)

\[
\text{Min} Z = \sum_{k=1}^{K} \sum_{j=1}^{N} x_{0,jk} f_k + \sum_{k=1}^{K} \sum_{i=0}^{N} \sum_{j=0}^{N} d_{ij} x_{ijk} p_r + \varepsilon_1 \sum_{i=1}^{N} \max\{E_i - t_i, 0\} + \varepsilon_2 \sum_{i=1}^{N} \max\{t_i - L_i, 0\} 
\]  

(6)

\[
\sum_{i=1}^{N} q_i y_{ik} \leq Q k = 1, 2, ..., K 
\]  

(7)

\[
\sum_{k=1}^{K} y_{ik} = 1, i = 1, 2, K, N 
\]  

(8)
\[
\sum_{j=1}^{N} x_{0jk} - \sum_{j=1}^{N} x_{0kj} = 0, \forall k \tag{9}
\]
\[
\sum_{j=0}^{N} x_{ijk} = y_{jk}, i = 1,2,K , N, \forall k \tag{10}
\]
\[
\sum_{j=0}^{N} x_{ijk} = y_{jk}, j = 1,2,K , N, \forall k \tag{11}
\]
\[
\sum_{j=1}^{N} x_{ijk} = y_{jk} \tag{12}
\]

Where: equation (5) is the maximum objective function of the average satisfaction; Equation (6) is the minimum objective function including fixed cost, transportation cost and penalty cost; Formula (7) Restrictions on maximum transfer of vehicles; Formula (8) ensures that each cell is served by only one vehicle; Formula (9) distribution vehicles start and end at the distribution center; Equations (10) - (11) ensure that each cell is served only once; Formula (12) the distribution vehicle shall, after serving colonel \( i \), be followed by captain \( j \).

3. Genetic algorithm design

3.1 Chromosome coding

Natural number coding is the coding method of this paper. Where, 0 represents the distribution center, 1,2...N is for community. Then, a chromosome representing the vehicle distribution path is constructed, which is added to the distribution path in turn under the constraints of time window and vehicle load, and finally a chromosome satisfying the constraint conditions is formed. Follow these steps until all distribution paths are created.

3.2 Fitness function

In the genetic algorithm, the higher value of fitness \( f \), the smaller the total cost objective function \( Z \). In this study, \( Z_i \) will represent the total cost of the \( i \)-th subpath. \( f(i) = 1/Z_i, i \in (1,2,...l) \)

3.3 Genetic manipulation

3.3.1. Strategy Select. Roulette as a hybrid strategy, in which elite selection mechanism is adopted.

3.3.2. Cross rule. In this paper, the partial matching crossover rule is used to prevent the genetic algorithm from getting into the local optimum and the result from getting the optimal value.

3.3.3. Mutation operation. Chromosome variation can help to produce new individuals and enhance local search ability. Two mutation points were randomly selected from the chromosome community points, and the genes in the paternal chromosomes were interchanged to produce the next generation of chromosomes.

4. Numerical examples validate

4.1The experimental data

The data in [11] are adopted in this paper. The information of the 15 community points is shown in table 1, and the distance between each community is shown in table 2. Specify parameters in the model: the running speed of the vehicle \( v=40 \text{km/h} \), the vehicle unit distribution cost is \( P_v=1.5 \), the fixed cost of each vehicle is \( f_k=85 \), \( e_1=50 \), \( e_2=100 \), and the maximum load of the vehicle is 250 units. In the genetic algorithm, the population size is 150, the crossover probability is 0.9, the mutation probability
is 0.05, and the maximum number of iterations is 200.

4.2 Analysis of calculation results

The path solutions obtained by using genetic algorithm in literature [11] are shown in table 2. As shown in table 2, the total cost is 499.8, the total path distance is 163.2, and the average \(C_T\) is 0.813.

| Community number | Coordinates X | Coordinates Y | Demand | Time window |
|------------------|---------------|---------------|--------|-------------|
| 1                | 12            | 5             | 75     | [7,8,10,11] |
| 2                | 3             | 22            | 63     | [7,8,10,11] |
| 3                | 5             | 17            | 52     | [7,8,10,11] |
| 4                | 8             | 30            | 17     | [7,8,10,11] |
| 5                | 11            | 32            | 6      | [7,8,10,11] |
| 6                | 14            | 16            | 42     | [7,8,10,11] |
| 7                | 6             | 9             | 37     | [7,8,10,11] |
| 8                | 11            | 28            | 29     | [7,8,10,11] |
| 9                | 17            | 6             | 49     | [7,8,10,11] |
| 10               | 22            | 18            | 55     | [7,8,10,11] |
| 11               | 24            | 5             | 12     | [7,8,10,11] |
| 12               | 6             | 19            | 59     | [7,8,10,11] |
| 13               | 22            | 21            | 67     | [7,8,10,11] |
| 14               | 17            | 20            | 35     | [7,8,10,11] |
| 15               | 14            | 28            | 88     | [7,8,10,11] |

The total cost of optimization using our model is 476.3, a total path distance of 141.5, and an average customer satisfaction of 0.805. Figure 2 is the path diagram for Table 3. As shown in the calculation results, under the same experimental data and parameters, the solution result of the model in this paper is better, with the total vehicle driving distance reduced by 15% and the cost reduced by 5% compared with that in the literature [11]. It can be seen from figure 2 and figure 3 that the model has obtained a
relatively satisfactory solution and the iterative convergence rate is fast. Therefore, our model is feasible and effective.

5. Conclusion
To address the specificity of community group purchasing fresh product distribution, this paper constructs a mathematical consumption model of distribution cost under the satisfaction function constraint of customer satisfaction and time window factors, analyzes fixed cost, transportation cost and time window penalty cost in detail, and then solves the problem using an improved genetic algorithm. Finally, the algorithm is verified by examples, and the algorithm is feasible and scientific with improved solution performance and convergence speed. At the same time, the satisfaction reached better rather than optimal, indicating that group purchasing platform enterprises cannot blindly pursue the lowest cost and ignore customer satisfaction. By comparing the existing literature, it is found that the research on the distribution path of community group purchase is worth further study.

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