Forward and reverse courier logistics distribution path planning based on multi-objective optimization genetic algorithm

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Abstract. In order to optimize the express logistics distribution path and improve the distribution efficiency, the multi-objective optimization model of express logistics distribution path with mixed time windows is proposed. The model takes into account the requirements of express substations for on-time arrival, express enterprises' control of logistics costs, quantifying customer satisfaction with on-time arrival rate, and constituting logistics costs with fixed costs and transportation costs. Based on the multi-objective optimization genetic algorithm, the Pareto solution set is obtained, and the optimal solution is selected by combining four evaluation methods. The feasibility of the method is demonstrated by applying the method to the case of a region in North China.

Keywords: multi-objective model, reverse logistics, genetic algorithm.

1. Introduction

At present, the national urban delivery market scale has exceeded trillions, and the consumption behavior of China's urban consumers has shown a trend of diversification, personalization, initiative, convenience and specialization. The situation prompts Chinese enterprises to start from the analysis of consumer behavior and develop and optimize urban route planning solutions to achieve high-efficiency distribution through clear market positioning of the enterprises themselves, so as to meet the needs of the consumer market.

Around the path optimization problem, more and more scholars have conducted research on it. Among them, in view of the superiority of genetic algorithm, Tian Shuaihui et al. proposed a multi-objective optimization with improved genetic algorithm for VRPTW, which constrains the distribution path through time window [1]; Xu Xiaofeng and Jiang Mingyue et al. integrated reverse logistics with distribution path [2]; Chang Haiping et al. conducted a relevant research on cold chain distribution path based on NSGA-II algorithm [3]; At the same time, although many scholars have explored the problem of path optimization, the comparison of the results of various algorithms is rarely involved . In this paper, we will take the express delivery path of a region as the research object, integrate the cost and customer satisfaction objectives of forward and reverse demand, and analyze the results of NSGA-II , NSGA-III and awGA , to arrive at a better solution [4-6].

2. Multi-objective optimization modeling of courier logistics distribution paths

2.1. Model Premise Assumptions

The truck distribution path optimization model is abstracted into a mathematical model, and the following assumptions need to be made for the convenience of model construction.

(1) The distribution path optimization study for an express terminal (hereinafter referred to as the terminal) and multiple express substations (hereinafter referred to as substations). The geographical location of the substation, forward and reverse logistics demand is known [7].

(2) The amount of goods at the terminus is equal to the sum of the required amount of goods at all sub-stations.

(3) The truck keeps a uniform speed in the distribution process.

(4) After the departure of the truck, no route changes can be made to the truck, and the starting and ending points of the truck are all express terminals.

(5) The truck either does not participate in the distribution, or can only be dispatched at the first time when the terminus starts to operate.

(6) Multi-site direct transportation

(7) A vehicle can serve multiple substations, but a substation can be served by only one vehicle.

(8) Satisfaction is only related to the on-time arrival rate of delivery trucks.

2.2. Model objective function construction

(1) Satisfaction goals

This paper assumes that satisfaction is only related to the on-time arrival rate of delivery trucks. In the process of delivery, the truck will consider various factors such as distance and demand and give priority to some substations for delivery, and the latest arrival time proposed by the substation is not guaranteed to be satisfied in all cases, and some express substations cannot deliver on time.

We use the mixed time window model with one-sided descent [8]. If the truck is late in delivery then its delivery time will be compressed, and if it is late for too long it will even directly lead to the sub-station express delivery task cannot be completed.

t_i, actual cargo arrival time; t_{ia}, expected cargo arrival time; t_{ib}, latest acceptable cargo arrival time.

$$\theta_i = \begin{cases} 1 & t_i \le t_{ia} \\ \dfrac{t_i - t_{ia}}{t_{ib} - t_{ia}} & t_{ia} < t_i \le t_{ib} \\ -\infty & t_i > t_{ib} \end{cases} \tag{1}$$

(2) Cost target

The total cost of express logistics distribution is divided into 2 components, namely fixed cost and variable cost.

Fixed Costs. It includes truck rental, driver's salary, etc. The fixed cost is only related to the trucks used for distribution, but not to the mileage of each truck. Fixed cost F can be expressed as

$$F = \sum_{m=1}^{M} f^m \tag{2}$$

Where: f^m is the fixed cost of truck m.

Variable cost. Variable costs include fuel consumption and maintenance costs of trucks, etc., which are related to the mileage of each truck, and the transportation cost V can be expressed as

$$V = \sum_{m=1}^{M} \sum_{i=0}^{N} \sum_{j=0}^{N} c_1 d_{ij} x_{ij}^m \tag{3}$$

Where: c_1 is the transportation cost per truck per kilometer; d_{ij} is the distance between substation i and substation j; x_{ij}^m is the decision variable. $x_{ij}^m = 1$ when truck m travels from substation i to to substation j for distribution service, otherwise $x_{ij}^m = 0$. In particular, the terminal is also called substation 0.

2.3. Establishing a multi-objective optimization model for express logistics distribution path

In summary, the express logistics multi-objective distribution path optimization model can be expressed as follows, where Q_{max} is the truck volume.

Decision Variables

$$y_i^m = \begin{cases} 1 & \text{Truck m for substation i distribution} \\ 0 & \text{Other} \end{cases} \tag{4}$$

$$x_{ij}^m = \begin{cases} 1 & \text{Truck m delivers from substation i to substation j} \\ 0 & \text{Other} \end{cases} \tag{5}$$

Objective function

$$\max \theta = \sum_{i=1}^{N} \theta_i \tag{6}$$

$$\min \mathrm{C} = \mathrm{F} + \mathrm{V} \tag{7}$$

Binding Conditions

$$\sum_{m=1}^{M} y_i^m = 1, i = 1, 2, \cdots, N \tag{8}$$

$$\sum_{i=1}^{N} x_{0i}^m = \sum_{i=1}^{N} x_{i0}^m \le 1, m = 1, 2, \cdots, M \tag{9}$$

$$\mathrm{Q}_0^{\mathrm{m}} = \sum_{\mathrm{i=1}}^{\mathrm{N}} \mathrm{y_i^m q_i} \le \mathrm{Q_{max}}, \mathrm{m} = 1, 2, \cdots, \mathrm{M} \tag{10}$$

$$Q_i^m = Q_{i-1}^m - \left(P_i - R_i\right) y_i^m \le Q_{\max}, m = 1, 2, \cdots, M, i = 1, 2, \cdots, N \tag{11}$$

3. Model solving design

3.1. Genetic algorithm solving

Since customer satisfaction and distribution cost are conflicting, both of them cannot reach the optimal level under mutual constraints, and the search space of the path planning problem is complex. Therefore, we use NSGA-II, NSGA-III and awGA in genetic algorithm to solve the problem, and compare the performance of the three to select the better one. In the set of searched Pareto solutions, a comprehensive evaluation is performed to derive the final path planning solution.

According to the characteristics of the problem, this paper uses the natural number all-around coding method. There are M trucks available and N substations need to be delivered. *1, 2, ... ,N* represent *N* substations . *N+1, N+2,... N+1, N+2, ..., N+M-1* represent the terminal (substation *0*).

(1) Complement 0 at the head and tail of the chromosome and set *N+1, N+2, ... , N+M-1* to 0

(2) Change multiple consecutive 0 to a single 0.

(3) Each minimal segment starting with *0* and ending with *0* represents the travel path of a truck.

According to the generation method of the code, the chromosome consists of *1, 2, 3, ... , N+M-1* natural numbers consisting of random full permutations. The chromosome is invalid in the presence of a truck overload.

3.2 Comprehensive evaluation

Since the objective function in this problem is only cost and customer satisfaction, a simple bi-objective comprehensive evaluation is performed. Therefore, the following simple four methods are used to obtain the optimal solution in the Pareto solution set in this paper. As shown in Table 1.

Table 1. Comprehensive Evaluation Methodology

	Method 1	Method 2	Method 3	Method 4
Indicators	θ/C	$1/C$	θ	$\theta - KC$
Restrictions	-	$\theta > 19$	C<3000	K=0.002

4. Example of an algorithm

4.1. Illustration

In order to verify the effectiveness of the algorithm, the actual situation in a city in North China is used as a reference to generate random arithmetic examples, and the details are as follows [9]. The volume of each truck is $7m^3$, the daily rent of each truck is *300* yuan, the truck travels at *0.7km/min*, and the travel cost per kilometer is *1* yuan per truck. The unit of time in the following table is *min*, the unit of distance is *km*, and the unit of volume is m^3. As shown in Table 2.

Table 2. Customer Needs Information

S/N	x	y	P	R	t_a	t_b	t_s	S/N	x	y	P	R	t_a	t_b	t_s
0	8.2	3.2	0	0	0	690	0	11	12.5	33.3	2.5	1.5	90	240	20
1	43.3	14.2	2.5	1.1	60	240	18	12	41.2	7.2	2.6	1.1	60	240	22
2	37.8	18.2	0.9	0.6	90	240	7	13	4.9	31	2.4	1.9	60	240	20
3	20.5	16.2	3.3	2	60	180	29	14	30.5	24.8	0.8	1.6	90	240	7
4	4.1	11.1	1.3	0.5	30	210	12	15	24.8	21.4	2.1	1.6	30	240	15
5	33.4	37.1	1.5	0.6	90	240	16	16	19.4	30.7	1.7	0.5	60	210	12
6	25.4	6.2	0.9	1	60	210	10	17	10.2	16.6	1.4	1.4	30	150	10
7	0.5	21.1	1.8	0.5	30	210	5	18	35.6	25	1.5	1.7	60	210	16
8	26.1	31.6	1.5	1.8	120	270	15	19	14.4	37.3	1.8	0.5	120	270	11
9	24.6	35.1	1	0.7	90	270	6	20	31.2	9.8	2.4	0.8	90	240	25
10	8.1	23.9	0.8	0.9	30	210	10								

4.2. Example calculation results

(1) Genetic algorithm for Pareto solution

The algorithm was solved using python, and the NSGA-II, NSGA-III, and awGA algorithm templates in geatpy were used to select the natural number full alignment coding method and modify each process accordingly, with chromosome validity considered for the initial population, crossover operation, and mutation operation [10].

To compare the performance of the three algorithms, the process of changing the mean value of the objective function of all individuals per generation of each algorithm was represented as a curve . As shown in Fig. 1.(The number of individuals in the population is 100, the number of evolutionary generations is 2000, the crossover probability is 0.9, and the variation probability is 0.005)

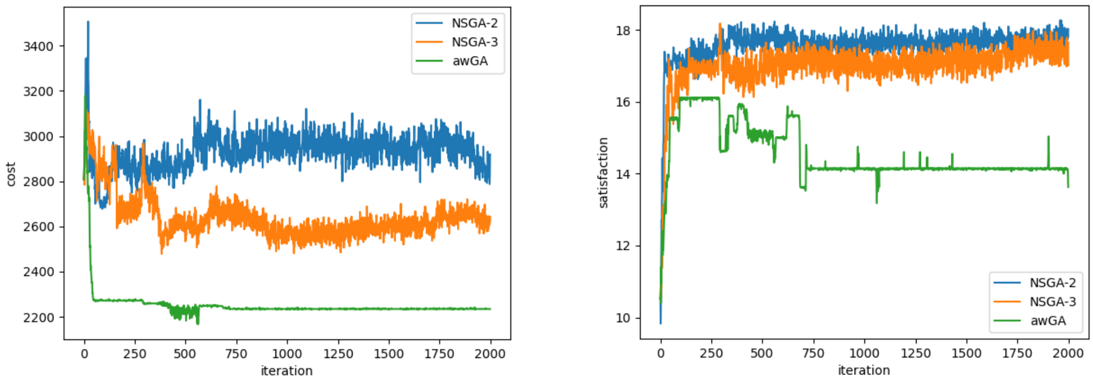

Fig. 1 Cost, customer satisfaction mean change

It can be seen to awGA has poor performance in customer satisfaction,and NSGA-II and NSGA-III have similar performance . So we finally choose NSGA-III. The pareto solution set solved by NSGA-III as shown in Fig. 2.

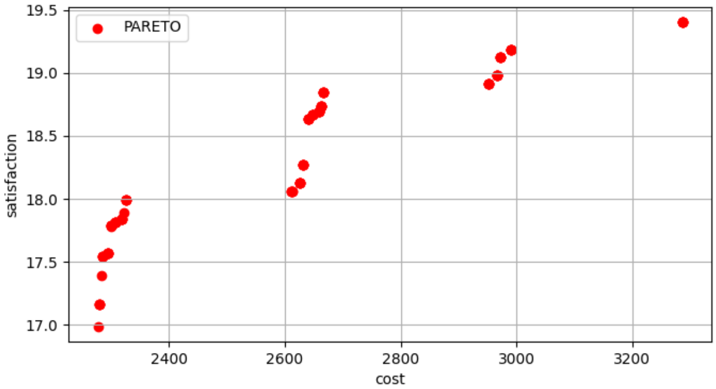

Fig. 2 Pareto solution set

(2) Comprehensive evaluation and optimal solution

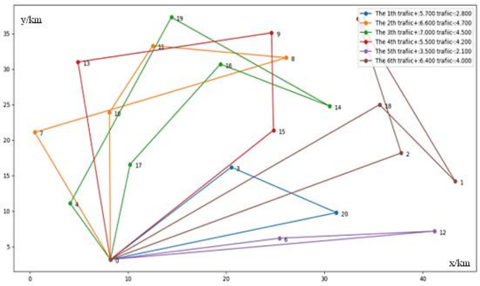

Fig. 3 Method 1 θ = 17.99 C = 2325

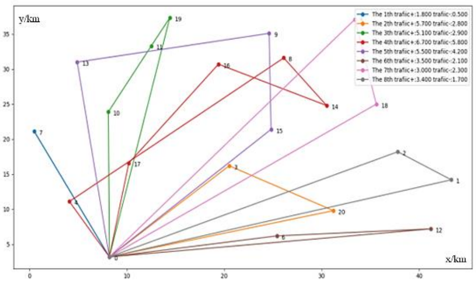

Fig. 4 Method 2 θ = 19.12 C = 2973

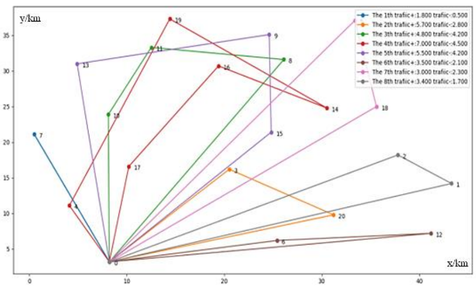

Fig. 5 Method 3 θ = 19.18 C = 2991

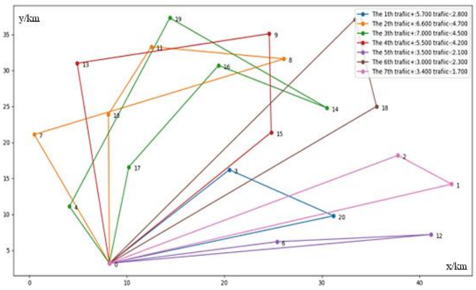

Fig. 6 Method 4 θ = 18.84 C = 2666

Based on the four integrated evaluation methods, the optimal solutions under the four perspectives are identified(Fig. 3, Fig. 4, Fig. 5, and Fig. 6).

5. Conclusion

With the objectives of maximizing customer satisfaction and minimizing logistics cost, a multi-objective optimization model of express logistics distribution path is established under the constraints of maximum vehicle load capacity, distribution continuity and mixed time window.

For the multi-objective problem, after comparing the performance of NSGA-II, NSGA-III and awGA, NSGA-III is used for the final solution. According to the characteristics of logistics distribution path, the chromosome full-arrangement coding is performed, and the load limit is used as the basis of chromosome validity test. The Pareto solution set is calculated, and four comprehensive evaluations are performed to select the optimal solution under different evaluation criteria.

The algorithm is validated by serving *20* customers . The Pareto solution set is selected from the results of the *500th* generation of the parent generation and evaluated comprehensively, and the final result is a more desirable value for each objective of the path, which proves the effectiveness and practical value of the model and algorithm.

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