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Research on Optimization of Urban Logistics Delivery Path Under Fuzzy Demand

Xuerui QIN and Hao CHEN[1]
School of Economics and Business Administration, Yibin University, Yibin City, Sichuan, China

Abstract. Optimization of delivery routes is a key method to reduce delivery costs. If scientific and reasonable methods are adopted to arrange delivery routes, it can reduce delivery costs, increase enterprise profits, and increase vehicle loading, achieving the goal of stable growth for enterprises. In this paper, the logistics distribution in the same city under the condition of fuzzy demand is taken as the research object, and the vehicle load, customer demand, customer service time and other constraints are taken as the constraints. The Simulated annealing algorithm is used to solve the model, and a reasonable and satisfactory optimization scheme is obtained. By comparing the solutions before and after optimization, it is confirmed that the optimization model can effectively solve the logistics distribution problem under fuzzy demand.

Keywords. Fuzzy, Demand, Path optimization, Simulated annealing algorithm, Optimization

1. Introduction

The logistics industry is a dynamic service industry that not only includes basic functions such as transportation, storage, loading and unloading, handling, and packaging, but also covers many fields such as circulation processing, distribution, and information processing. At the same time, with the continuous development of e-commerce, takeout, errands and other industries, local logistics and distribution have become a key carrier of urban services, facilitating customers' shopping and daily activities. With the continuous expansion of demand in the local logistics market, many internet companies have joined the competition of local logistics, bringing opportunities and challenges to local logistics enterprises. On the one hand, people's consumption concepts are gradually "personalized" and "diversified", and their awareness of time and service is becoming more sensitive. The ambiguity of local logistics needs is increasing, requiring logistics to be more efficient and convenient. On the other hand, at present, local logistics is still in a rough development stage, with low

[1] Corresponding Author, Hao CHEN, Yibin University, Yibin City, Sichuan, China; Email: 1312587451@qq.com
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levels of informatization, low resource utilization, and inconsistent technical standards and distribution processes, resulting in low transportation efficiency and high transportation costs of local logistics. It is crucial for local logistics enterprises to effectively meet diverse customer needs, develop reasonable distribution path strategies, reduce distribution costs of local logistics, and improve customer satisfaction.

Optimization of distribution routes is an important way to reduce logistics transportation costs and improve logistics transportation efficiency. On this basis, it is also necessary to consider that fuzzy demands may often be encountered in actual situations. In such cases, conducting distribution routes for local logistics effectively reduces the operating costs of local logistics enterprises, which has important practical significance. Ouyang jingcan proposed the vehicle path optimization model uses heuristic algorithms to obtain solutions with low delivery costs, high vehicle loading rates, high service efficiency, and high profits, which has important theoretical significance[1].

The optimization of distribution paths is a hot research topic in the field of logistics. Carlsson et al. proposed the concept of upper and lower limits for time windows, where the upper limit refers to the time when customers can provide service as early as the delivery vehicle is specified, the lower limit refers to the latest service time, and the intermediate time is the service time[2]. Tao introduces soft time window constraints on the basis of time windows and solves related problems considering time factors by establishing penalty functions[3]. Eslamipoor Reza believes the pollutant of environment is considered an influential factor in the evaluation and selection of the supplier. The suggested model's objectives include lowering the cost of suppliers, minimizing low-quality goods from suppliers, minimizing delivery time, and minimizing the amount of environmental pollutants emitted by vehicles [4]. MA aims to minimize distribution cost and maximize customer satisfaction, he design an improved ant colony algorithm to solve the initial distribution path and use the insertion method to solve the immediate customer demand. [5]. Lisa et al. mainly studied the construction of cold chain distribution models, combined with the distribution data of cold chain companies, and used Matlab programming tools and commonly used hybrid mutation probabilities to obtain optimization results[6].In recent years, research on path planning and algorithms in China has also been greatly strengthened. Wei Junhua divided it into soft time window path problems based on customer needs and established a model, which was solved and optimized using genetic algorithm[7]. Ma Cunrui et al. constructed a path optimization model suitable for express delivery, implemented the solution using genetic algorithm, and conducted sensitivity analysis through actual cases[8]. Scholars like Deng Xueping have turned their attention to express delivery recycling, designing an objective function of distribution cost plus recycling processing cost, constructing relevant recycling models and solving them. Using genetic algorithms to solve, while considering other factors, the optimal solution for the delivery path is obtained[9]. Researchers such as Zhang Duo used an improved genetic algorithm and a multi criteria decision-making method to solve the capacity constrained vehicle delivery problem, taking into account various goals such as carbon emissions and road risks[10].

Current research indicates that foreign scholars are more focused on considering the impact of different time window constraints on path optimization and conducting research on them. However, domestic scholars focus on how to obtain the optimal solution for path optimization under different constraint conditions. Overall, there is still a lack of research on the optimization of logistics delivery paths with fuzzy demands. There are few research results on fuzzy requirements, especially those that consider both dynamic and stochastic demand changes with strong randomness, such as the location and range of changes.

On the basis of summarizing existing literature, this article proposes to establish an optimization model for urban logistics distribution path under fuzzy demand, build an optimization model for urban logistics distribution path with the minimum total operating cost. The vehicle path optimization model for the constructed fuzzy demand is transformed into a fuzzy demand response problem and a delivery path update strategy problem, and Simulated annealing algorithm is designed to solve the vehicle routing. Finally, take Anji logistics distribution enterprises in Yibin City as an example, select data from 12 distribution points in 1 distribution center to verify the effectiveness of the construction model and solution. By comparing the optimal path for demand determination and different $\left(\mu,\sigma^2\right)$ values, it has been confirmed that the model and algorithm have good application value.

2. Construction of an Optimization Model for Urban Logistics Distribution Path Based on Fuzzy Demand

2.1. Problem Description

The fuzzy demand based distribution path optimization problem is a vehicle path optimization problem that considers fuzzy demand. Compared to the conventional VRPTW problem, it expands the determined cargo demand and time window demand into a dynamic vehicle path optimization problem that considers changes in cargo demand and new demands. The vehicle routing optimization problem with fuzzy demands can be specifically described as: in a distribution system, there is a fixed distribution center and several distribution vehicles, where some customers' demands are accurate, while the demands of other demand points may change, known as fuzzy demand points.

As the demand for new fuzzy points arises, the delivery system must respond with delivery. Under certain constraints, arrange the delivery path of vehicles reasonably to achieve the minimum cost during the delivery process and meet the delivery requirements of fuzzy demand points to the greatest extent[11-13].

2.2. Model Assumptions

The following assumptions are made for the optimization of vehicle routing in urban logistics distribution under fuzzy demand:

(1) In the distribution system, there is a distribution center and multiple distribution points. Each delivery vehicle departs from the distribution center, completes the task of the distribution point, and returns to the distribution center.

(2) All delivery vehicles are subject to load limitations, which can result in varying transportation costs.

(3) In the distribution point, factors such as the location and quantity of demand points are clearly defined; The demand for fuzzy demand points is uncertain.

(4) The demand for goods at any demand point, whether vague or explicit, shall not exceed the maximum carrying capacity of a single vehicle.

(5) The mileage between the distribution center and demand points, as well as between demand points, is fixed.
(6) Once the demand for fuzzy requirements appears, there will be no change.

2.3. Construction of Fuzzy Demand Delivery Path Optimization Model

2.3.1 Parameter Description

The parameter assumptions are shown in Table 1.

Table 1 Parameter Definition

Symbol	Define	Symbol	Define
N	The number of customers that the enterprise needs to serve, when 0 is taken as the distribution center point	FC	Penalty costs
K	Number of vehicles required for delivery	M_a, M_b	Time penalty coefficient
Q	Vehicle load capacity	S_{ik}	The time when vehicle k starts serving customer i
GC	Vehicle Fixed cost	a_i	The time when the vehicle can access customer i
f_k	Fixed cost of the kth vehicle operation	b_i	The time when the vehicle can leave customer j
TC	Vehicle Variable Cost	q_i	The freight demand Customer i
d_{ij}	The shortest distance between delivery point i and delivery point j	X_{ijk}	Decision variable, vehicle k is 1 when transporting from delivery point i to delivery point j, otherwise it is 0
α_k	Unit distance cost of vehicle k	Y_{ik}	Decision variable, using vehicle k to serve customer i

2.3.2 Objective function

(1) Vehicle Fixed cost

Fixed cost of vehicles refer to fixed expenses such as staff salaries and maintenance costs incurred during the normal operation of vehicles, which are recorded as:

$$GC = \sum_{k=1}^{k} f_k \tag{2-1}$$

(2) Variable cost of transportation

During the transportation process of vehicles, variable costs refer to the costs that vary with the distribution mileage and load capacity, including labor, fuel consumption, electricity consumption, etc. For ease of calculation, the variable cost in this article is simply expressed as an equation related only to the delivery mileage, which is:

$$TC = \sum_{k=1}^{k} \sum_{i,j=1}^{n} X_{ijk} \cdot d_{ij} \cdot \alpha_k \tag{2-2}$$

2.3.3 Constraint condition

Visiting the customer's vehicle is the same as leaving the customer's vehicle.

$$\sum_{n=1, n \neq i \neq j} X_{ink} = \sum_{n=1, n \neq i \neq j} X_{njk}, k \in K \tag{2-3}$$

Ensure that all customers receive only one service.

$$\sum_{i \in N} Y_{ik} = 1 \tag{2-4}$$

The starting and ending points of each delivery vehicle are the distribution centers.

$$\sum_{j\in N} X_{0jk} = \sum_{j\in N} X_{i0k} = 1, k\in K \tag{2-5}$$

The total customer demand on each delivery route must be less than the capacity limit of the vehicle.

$$\sum_{i\in N}\sum_{k\in K} q_i Y_{ik} \le Q \tag{2-6}$$

2.3.4 Construction of optimization model

Optimize the model with the goal of minimizing costs:

$$\begin{aligned}
&\min C = \sum_{k=1}^{k} f_k + \sum_{k=1}^{k}\sum_{i,j=1}^{n} X_{ijk}\cdot d_{ij}\cdot \alpha_k \\
&s.t. \\
&\sum_{n=1,n\neq i\neq j} X_{ink} = \sum_{n=1,n\neq i\neq j} X_{njk}, k\in K \\
&\sum_{i\in N} Y_{ik} = 1 \\
&\sum_{j\in N} X_{0jk} = \sum_{j\in N} X_{i0k} = 1, k\in K \\
&\sum_{i\in N}\sum_{k\in K} q_i Y_{ik} \le Q
\end{aligned} \tag{2-7}$$

3. Algorithm Solution for Fuzzy Demand Intracity Logistics Delivery Path

Simulated annealing algorithm is a stochastic optimization algorithm based on Monte Carlo iterative solution strategy. Its starting point is based on the similarity between the annealing process of solid materials in physics and general Combinatorial optimization problems. The goal is to provide effective approximate solution algorithms for problems with NP complexity. Overcoming the defects of easily falling into local minima and dependence on initial values in other optimization processes. Theoretically, it is a global optimization algorithm. Based on the similarity between the solution of the optimization problem and the annealing process of the Physical system, it uses the Metropolis algorithm and properly controls the temperature decline process to achieve Simulated annealing, so as to achieve the purpose of solving the global optimization problem. The specific steps include:

(1) Set the initial scheme with the objective function T as sufficiently large and use it as the initial solution, with a design termination iteration count of N;

(2) For n=1, Do steps (3) to (5) for N;

(3) Generate a new solution X and calculate the difference between the new solution X and the previous solution, denoted as $\Delta E(X)$;

(4) If $\Delta E(X)$, then accept X as the new current solution, otherwise accept X as the new current solution with probability exp($^{-\Delta E(X)}\!/_{T}$);

(5) If sufficient search or termination conditions are met, output the current solution as the optimal solution and end the program;

(6) Gradually decrease T until it approaches 0, then proceed to step (2).

Simulated annealing algorithm flow is shown in Figure 1.

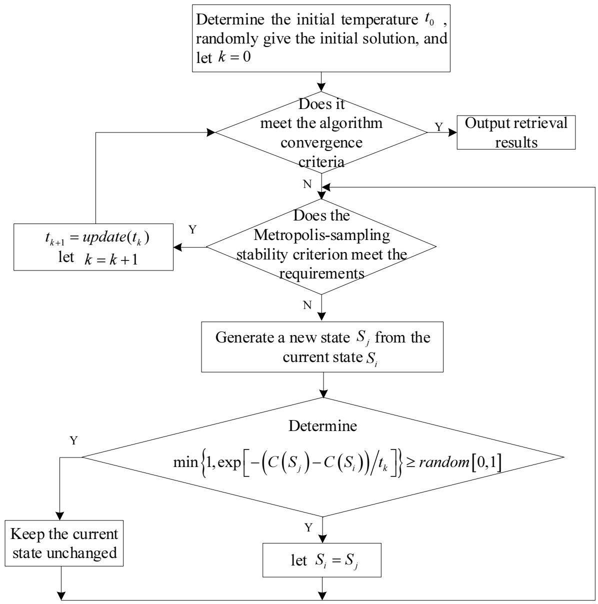

Figure 1 Flow chart of Simulated annealing algorithm

4. Example

This paper takes Yibin Anji Logistics Company as an example. The company has its own logistics distribution center, warehouse and its own distribution team, whose main job is to deliver products to supermarkets and stores. Anji logistics company currently has 12 customer points for delivery services, with 12 delivery vehicles. The distribution center provides services to customers between 4 and 6 a.m. every day to ensure customers' demand on that day and avoid urban traffic peak. The coordinates of the customer point and distribution center are known; The expected demand is known, but the actual demand follows an independent Normal distribution; The maximum load capacity of a single vehicle is 2 tons. The specific parameters are shown in Table 2.

Table 2 Demand Point Information Parameter Table

Point	X	Y	Demand	Point	X	Y	Demand
0	14.07	30.67	/				
1	13.45	30.31	0.43	7	13.77	29.57	0.52
2	13.83	30.04	0.47	8	15.04	29.59	0.72
3	14.21	29.15	0.75	9	16.02	30.45	0.49
4	13.45	30.42	0.51	10	14.56	29.77	0.49
5	11.56	28.51	0.90	11	15.27	28.54	0.86
6	15.57	30.51	0.83	12	16.55	29.57	0.89

According to the basic data in Table 1 and the relevant assumptions in the model, this paper uses Matlab to write code, set the values of relevant parameters in the Simulated annealing algorithm, set the initial temperature T_0=999 , termination temperature T_f=0.001 , temperature attenuation parameters $\alpha = 0.93$, Markov chain length $M_k = 20$, and Fixed cost of 120 yuan/vehicle, Variable cost 2 yuan/km.

(1) When the requirements are clear

The relevant parameters and initial values are imported into Matlab for solution, and the optimal results are obtained after 50 random tests. The convergence and scheme of Simulated annealing algorithm after iteration are shown in Figure 2, and the distribution scheme is shown in Table 3. It can be seen that after iteration, the algorithm begins to converge after 120 iterations, and the total delivery cost in the optimal state is 648.08 yuan.

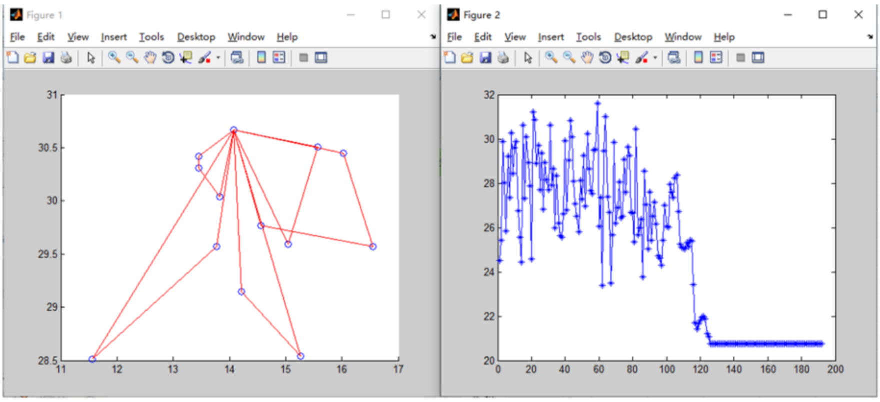

Figure 2 Distribution Plan and Convergence Curve

Table 3 Delivery Plan

Number	Delivery Plan	Distance(km)	Cost(yuan)	Actual Capacity(m²)	Load factor(%)
1	0-2-1-4-0	1.92	123.84	1.41	70.50%
2	0-3-11-0	5.19	130.38	1.61	80.50%
3	0-6-8-0	4.02	128.04	1.55	77.50%
4	0-10-12-9-0	6.01	132.02	1.87	93.50%
5	0-7-5-0	6.90	133.80	1.42	71.00%
Total		24.04	648.08		

(2) When demand is ambiguous

When the demand is fuzzy, it is calculated by 90% of the demand satisfaction rate, and the customer demand meets the Normal distribution $X \sim N\left(\mu,\sigma^2\right)$. To simplify the solution of the Normal distribution, according to the relevant knowledge learned, z is 1.3 at that time $x=\mu+z\sigma$, and the change of demand of each customer point under the condition of obeying the Normal distribution is shown in Table 4.

Table 4 Normal distribution Change of Customer Point Demand

Demand point	Expected demand	σ =0.1	σ =0.2	σ =0.3	Demand point	Expected demand	σ =0.1	σ =0.2	σ =0.3
1	0.43	0.56	0.69	0.82	7	0.52	0.65	0.78	0.91
2	0.47	0.6	0.73	0.86	8	0.72	0.85	0.98	1.11
3	0.75	0.88	1.01	1.14	9	0.49	0.62	0.75	0.88
4	0.51	0.64	0.77	0.9	10	0.49	0.62	0.75	0.88
5	0.9	1.03	1.16	1.29	11	0.86	0.99	1.12	1.25
6	0.83	0.96	1.09	1.22	12	0.89	1.02	1.15	1.28

Through Matlab software calculation, convergence occurs approximately 130 times when the demand is fuzzy. The summary of path optimization under fuzzy requirements is shown in Table 5.

Table 5 Path optimization based on random requirements

Delivery vehicle	σ =0.1	σ =0.2	σ =0.3
1	0-4-1-2-0	0-10-11-0	0-6-0
2	0-9-10-7-0	0-2-6-0	0-11-0
3	0-12-6-0	0-12-9-0	0-12-0
4	0-11-8-0	0-8-3-0	0-2-3-0
5	0-3-5-0	0-4-1-0	0-8-9-0
6		0-7-5-0	0-1-4-0
7			0-10-7-0
8			0-5-0
Total mileage	24.77	26.10	31.53
total cost	649.53	772.19	1023.05

5. Conclusion

This paper mainly conducts relevant analysis based on the actual situation of Anji Logistics Company in Yibin City. After collecting relevant data, it conducts research and analysis. Assuming that the demand of customer points follows a certain Normal distribution, it then uses Matlab software to write programs to solve the model built by Simulated annealing algorithm according to its location distribution, demand and other conditions, and conducts quantitative analysis on the basis of the model, Finally, the path optimization results for minimizing delivery costs under deterministic and fuzzy demands are obtained. The various costs under deterministic and fuzzy demands are compared, and the results are compared and analyzed to verify the effectiveness of this study.

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