

Research Article

Research on Logistics Distribution Vehicle Path Optimization Based on Simulated Annealing Algorithm

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With the continuous development of Internet technology, e-commerce has gradually become a popular field. As an important part of China's tertiary industry, the rapid development of e-commerce has played a huge role in promoting the development of the domestic economy. At the same time, e-commerce has also greatly contributed to the development of the logistics industry. Hence, with the rapid growth of the economy and the rapid development of e-commerce, the construction of logistics and distribution systems plays an essential role in the process of urban development. A perfect logistics and distribution system can promote the overall economic efficiency of the city and facilitate people's daily lives. In addition, the development of logistics systems can meet the escalating needs of consumers and the increasingly competitive market environment, thus promoting the transformation of e-commerce retail enterprises to high-quality development. The simulated annealing algorithm is an effective approximation algorithm for solving optimization problems, and the application of this algorithm to path optimization problems can be of practical value in solving problems in urban road traffic and logistics distribution. Therefore, exploring logistics distribution vehicle route optimization is of great practical significance to optimize the allocation of resources in cities, improve the economic efficiency of enterprises, and solve the problems of urban traffic congestion and can provide reference for relevant departments in their decision-making. This paper focuses on how to optimize vehicle paths in the logistics distribution process and constructs a path optimization model that satisfies the multiobjective premise. The path problem is solved using the simulated annealing algorithm, and the results are analyzed.

1. Introduction

E-commerce is developing rapidly in China and has made positive contributions in promoting consumption, developing foreign trade, and driving the digital development of industries. The development of new models such as live-streaming with goods and community group buying continues to stimulate and meet diversified consumer needs [1]. In terms of promoting consumption, the rapid development of e-commerce has accelerated the application and updating of new technologies such as artificial intelligence, big data, and the Internet of Things, driving the upgrading of consumer experience [2]. In terms of developing foreign trade, e-commerce enterprises have continued to expand their international shipping routes, attracting more and more overseas sellers and promoting the continuous improvement of China's e-commerce foreign trade system [3]. In terms of

expanding employment, the integration of e-commerce with the real economy has driven more and more people into the e-commerce industry [4]. In terms of driving the digital development of the industry, e-commerce has deeply integrated with the real enterprises, integrating technology, capital, logistics, services, and upstream and downstream enterprises through the horizontal and vertical supply chains, respectively, promoting the development of efficient supply chain synergy and supply-side smart manufacturing [5]. Today, e-commerce has become an important driving force in stabilizing economic growth and high-quality development in China's consumer market.

Nowadays, in the context of the rapid development of e-commerce, logistics and distribution have also undergone great changes. The logistics and distribution industry realizes innovative ways of providing logistics services, completes resource sharing, and promotes the development of the

overall level of logistics management [6]. Compared with traditional forms of logistics and distribution, logistics and distribution under e-commerce need to rely more on information technology to optimize management methods and obtain maximum social and economic benefits with convenient and scientific management processes. Under e-commerce, logistics management can meet the needs of customers to the maximum extent possible, with diverse management methods, integration of information technology, from the actual situation of the warehouse, optimization of orders, and reasonable choice of delivery methods, to achieve efficient communication and sharing of resources and information throughout the management process. Also, logistics management can be made more efficient, save management costs, and improve management efficiency.

Although the logistics industry in China has made great progress in terms of infrastructure, information systems, and other conveniences, there are still some problems that occur in the logistics and distribution process. One of the serious problems is the operation of empty vehicles [7, 8] and unreasonable route settings [9]. These issues have directly led to increased operating costs and lower service levels for enterprises. On the other hand, along with the continuous development of cities, the ownership of motor vehicles is getting higher and higher. Meanwhile, the road congestion in urban traffic is becoming more and more serious, which directly affects the urban logistics and distribution process [10]. At the same time, the route of the vehicle in the distribution process is affected by a number of links and factors, which directly determines the cost and efficiency of the enterprise [11, 12]. In reality, optimizing logistics and distribution routes helps to build a perfect social service system and protect the interests of the people. A social service system is a comprehensive service system that combines government public services and self-service for the people. It plays an important role in enhancing the interests of society, enterprises, and people. In this system, logistics and distribution play an important role. With the rise of e-commerce and the Internet, logistics is playing an increasingly important role in everyday life. In this context, the optimization of logistics and distribution routes can contribute to the establishment of a perfect urban transport model, which can largely improve the orderliness of society and promote the overall level of service. Therefore, the path problem needs to be planned scientifically and rationally in order to meet the needs of customers, improve the efficiency of distribution, reduce costs, and realize the optimization of resource allocation, which is also an important part of the distribution process.

In the e-commerce environment, although the logistics distribution industry has undergone great changes, it has also encountered some issues. Firstly, there is a lack of a perfect management system [13, 14]. The scale of some logistics enterprises is small, and they are not timely enough in terms of access to information. Coupled with the existence of the regional industry monopoly phenomenon, resulting in the collection of management link commodity information and the unreasonable choice of distribution methods, it is difficult

to meet the actual needs of customers, which restricts the development of logistics enterprises [15]. Secondly, logistics enterprises lack the sense of innovation [16, 17]. Most logistics enterprises still adopt the traditional management mode, which makes it difficult to efficiently use the resources within the enterprise and improve the circulation speed of commodities, resulting in the loss of customer sources [18]. The lack of professional logistics management talents is also a problem [19]. Many enterprises do not pay attention to the introduction and training of logistics talents, which is not conducive to improving the service capacity of the talent positions as well as the logistics management level [20, 21]. To be specific, the remuneration system of talents is unreasonable, which leads to a high mobility of logistics management talents and affects the management process [22]. Furthermore, some logistics industries have led to many environmental problems due to unregulated links in the distribution process [23–25]. In addition, most logistics companies lack research on national policies and legal systems related to the logistics industry and lack the motivation to actively seek help from the government when the management process touches the legal boundaries, leading to inefficiency in the actual management process.

In the context of the booming e-commerce and logistics industry, it is of great practical importance to study the problem of optimizing the path of vehicles in the distribution process. With the rapid development of e-commerce, the Internet dividend is gradually disappearing and the growth rate of retail sales is gradually slowing down. In order to maintain their market share, major e-commerce companies have sought to shift to new technologies, new models, and new business models to cater to the upgraded consumer demand [26, 27]. A reasonable urban logistics distribution route not only helps to improve the economic efficiency of transport enterprises but also helps e-commerce enterprises to improve their efficiency in this aspect of distribution. The efficient logistics and distribution model takes the lowest distribution cost, the lowest distribution time, and the shortest distribution distance as the optimal distribution objectives [28]. However, in the real logistics and distribution process, it is difficult to achieve all three objectives at the same time. Therefore, this problem can be solved through the rational planning of logistics distribution paths, ultimately reducing transport costs, minimizing transport time and redundant transport links, making the distribution process more rational, and improving the overall economic efficiency of logistics enterprises.

To sum up, a proper logistics distribution path can improve the economic efficiency of transport enterprises by reducing transport costs. At the same time, it reflects the service level of transport enterprises in the process of distribution to customers, increases the service satisfaction of transport enterprises, and has a great role in promoting the development of transport business and e-commerce industry. More importantly, as an important part of the social service system, a reasonable logistics distribution route can contribute to the overall economic and social development of the city and promote the construction and improvement of the urban service system.

2. Vehicle Path Optimization Model

2.1. Vehicle Path Problem. The vehicle path problem (VPP) is not only a key research element in the field of logistics distribution but also a research hotspot in all transport problems. As a multidisciplinary theory that integrates logistics, operations research, advanced mathematics, and computer science, the wide range of applications of VPP and the economic benefits it brings have received a great deal of attention from related industries [29]. As shown in Figure 1, VPP refers to the distribution center providing goods to customers according to their requirements, in which a reasonable route of travel needs to be organized to complete the connection between different loading and unloading points [30]. While satisfying the customer's requirements regarding the amount of goods demanded and the delivery time of goods, it is necessary to achieve the distribution objectives such as the shortest transport mileage, the shortest transport time, and the lowest transport cost under the constraints of transport vehicle capacity, vehicle loading and unloading methods, and traffic road conditions.

VPP has been studied for many years and has produced many different variations by combining it with practical situations. This study classifies VPP into two categories according to the constraints of the solution objective: one is the static vehicle path problem (SVPP) and the other is the dynamic vehicle path problem (DVPP) [31, 32]. The detailed category of VPP is shown in Figure 2.

SVPP means that the customer points and related factors associated with this delivery are confirmed before the distribution vehicle performs that delivery task. In other words, the route of the delivery vehicle for that delivery task is already planned. On the contrary, DVPP refers to the existence of a variety of uncertainties throughout the distribution process, usually including customer demand and dynamic traffic conditions, which can affect the planning of the route during the distribution process.

2.2. Logistics Distribution Process. Logistics distribution is characterized by high distribution frequency, low volume, extensive travel, and vehicle-based distribution. On the basis of the distribution points of the logistics distribution center and the distribution locations chosen by customers, the distribution routes are further optimized to ultimately reduce costs and improve the performance level of the company in order to achieve the goals of high efficiency, low cost, and high quality. The whole transportation process of logistics distribution is shown in Figure 3.

VPP requires the consideration of different target factors in the research. This means that different indicators need to be considered in a comprehensive manner, but in practice there are generally incompatibilities between some of them. For example, there is a contradiction between ensuring that the needs of the customer are met to the greatest extent possible and reducing the cost of the distribution process. Through scientific and rational planning of each link in the distribution process, different objectives are weighed and corresponding strategies are made based on various influencing factors.

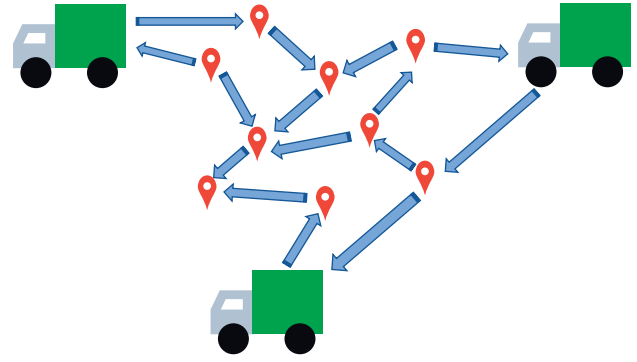


FIGURE 1: Vehicle path problem.

Eventually, the goal of reducing distribution costs and improving customer satisfaction can be achieved, and the efficiency of logistics enterprises can be improved.

In general, the logistics distribution path optimization model needs to consider several factors, such as distribution centers, distribution vehicles, target customers, and distribution routes. The interrelationship of these factors is shown in Figure 4.

In current practical route planning problems, not only a single objective can be considered but also multiple objectives for delivery vehicles, delivery routes, and customer needs. Therefore, a multiobjective VPP problem is specifically a problem where the constraints are met, a model is constructed using operations research and applied mathematics, and the algorithm is solved using computer theory to arrive at the optimal distribution path with multiple objectives. In general, the mathematical model of a multiobjective optimization problem can be expressed as follows:

$$\min f(x) = [f_1(x), f_2(x), f_3(x), \dots, f_i(x)], \quad (1)$$

such that

$$y_j(x) \geq 0, \quad j = 1, 2, \dots, n, \quad (2)$$

where x refers to the decision variable, $f_i(x)$ is the objective function, and $y_j(x)$ refers to the constraint.

Logistics distribution belongs to the typical traveler's problem, where a traveler starts from one city, traverses each location once and only once, and finally returns to the starting location. Assume that the scheme number of the traversal path is $P = \{1, 2, \dots, a\}$. In addition, $D(W_i, W_{i+1})$ refers to the distance between the i th location and the $(i+1)$ th location. Then, the following model can be constructed:

$$\min T_D = \sum_{i=1}^{a-1} D(W_i, W_{i+1}) + D(W_a, W_1), \quad (3)$$

such that

$$\sum_{i=1}^a p_i - \sum_{j=1}^a p_j = 0. \quad (4)$$

2.3. Simulated Annealing Algorithm. VPP arises from the reality of logistics and distribution processes. In distribution

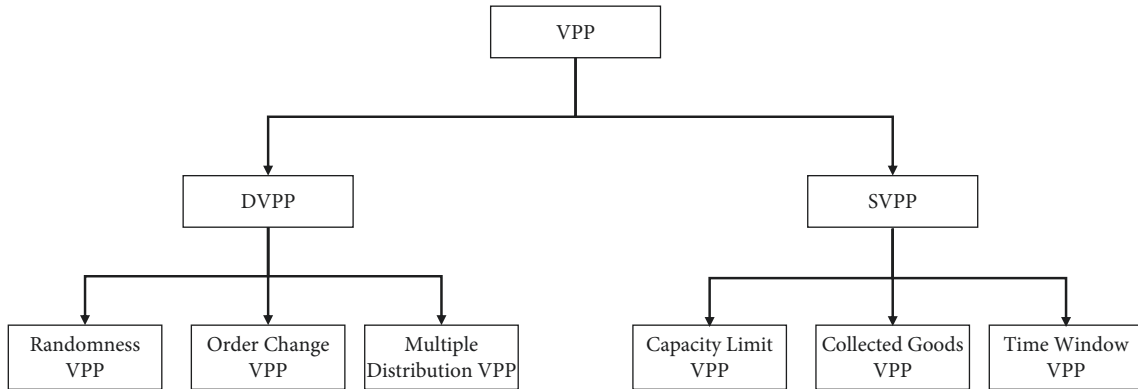


FIGURE 2: Category of vehicle path problem.

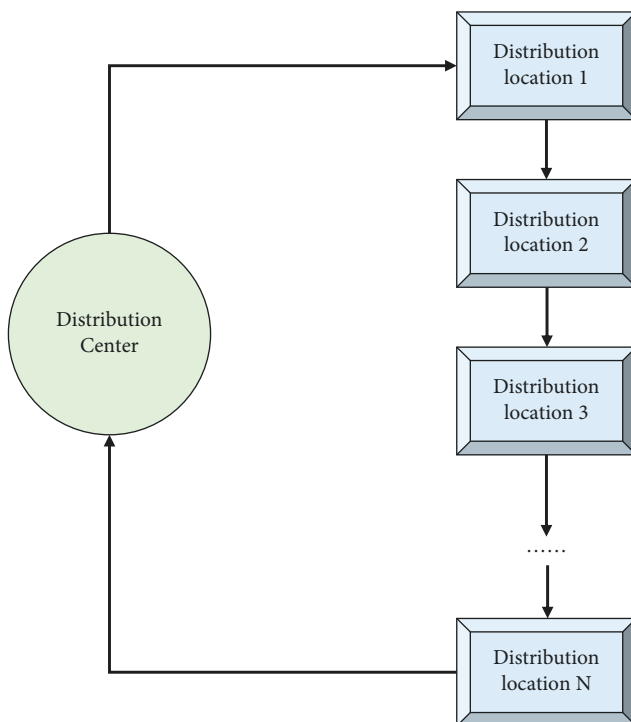


FIGURE 3: Transportation process of logistic distribution.

systems, managers are required to adopt efficient distribution strategies in order to improve service levels and reduce freight costs. Many algorithms have been developed to optimize the vehicle routing problem, such as genetic algorithms, ant colony algorithms, and forbidden search algorithms. However, as the vehicle routing problem is a typical nondeterministic polynomial problem, the exact solution is only possible when the number of demand points and road sections is small, so in general, it is difficult to obtain a globally optimal or satisfactory solution.

Simulated annealing is a heuristic algorithm which, unlike the usual local search algorithm, extends the local search algorithm to a global search algorithm. The simulated annealing algorithm is derived from the simulation of the annealing process in thermodynamics, where the algorithm is able to give an approximate optimal solution in polynomial time by slowly decreasing the temperature parameter

at a given initial temperature. It is a theoretical global optimum algorithm that selects with a certain probability the state in the neighborhood where the target value is relatively small. The principle of the simulated annealing algorithm is shown in Figure 5.

The simulated annealing algorithm simulates the cooling process of a classical particle system in thermodynamics and is used to solve the extrema of a planning problem. When the temperature of a system of isolated particles decreases at a sufficiently slow rate, the system is in approximate thermodynamic equilibrium and eventually the system will reach its lowest energy state, which corresponds to the global minima of the energy function [33]. The general combinatorial optimization problem has specific similarities to the annealing process, and Table 1 compares the two, suggesting that the optimal solution to the combinatorial optimization problem can be investigated by simulated annealing algorithms.

The elite set-based multiobjective simulated annealing algorithm is a multiobjective simulated annealing algorithm formed by combining the quality solution retention strategy of the genetic algorithm. The advantage of this algorithm is the retention of the high-quality solution set from the genetic algorithm and follows the nondominated ranking operator and the density comparison operator. The parent solution retains the high-quality solution, and the high-quality solution set continues to be combined with the offspring to produce more offspring high-quality superior value solutions. The multiobjective simulated annealing algorithm based on elite sets is effective in avoiding the loss of high-quality solutions of the parents in neighborhood search. The results are presented as noninferior solution sets in a two-dimensional coordinate system, which allows visualization of the characteristics of each solution set. Therefore, this algorithm can provide effective decision support for path optimization problems in the logistic distribution process.

The solution process of the simulated annealing algorithm is shown in Figure 6.

The detailed description about the solution process of the simulated annealing algorithm is as follows:

- (1) Choose the initial path S_1 , determine the initial temperature T_1 , set the current path $S_i = S_1$ and the

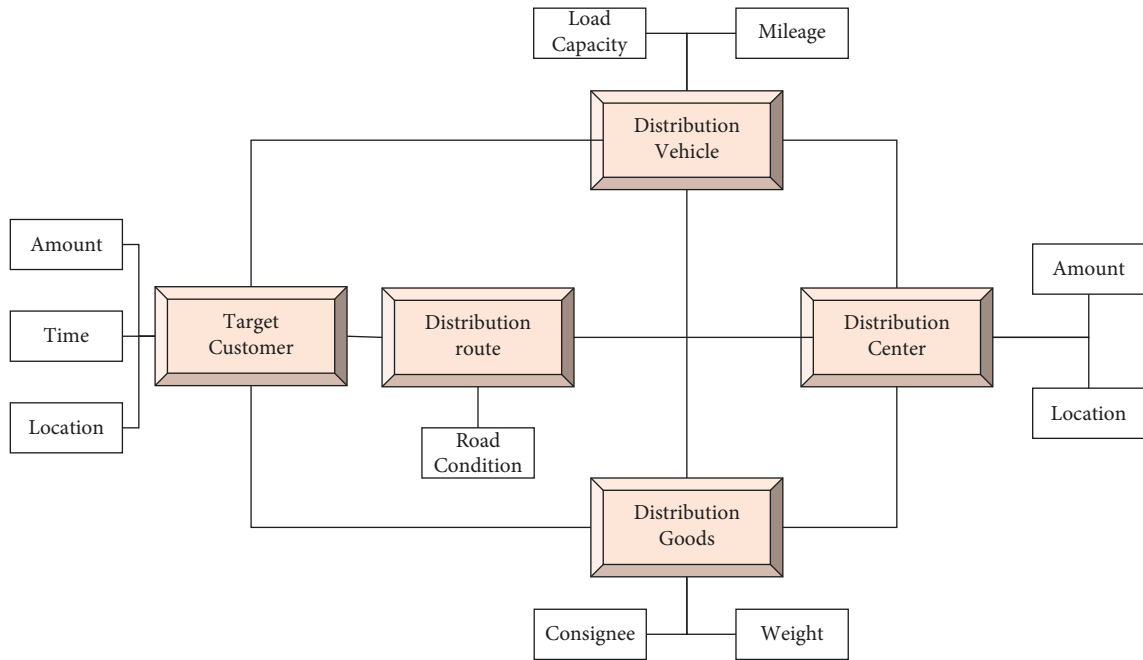


FIGURE 4: Interrelationship of the factors affecting logistic distribution.

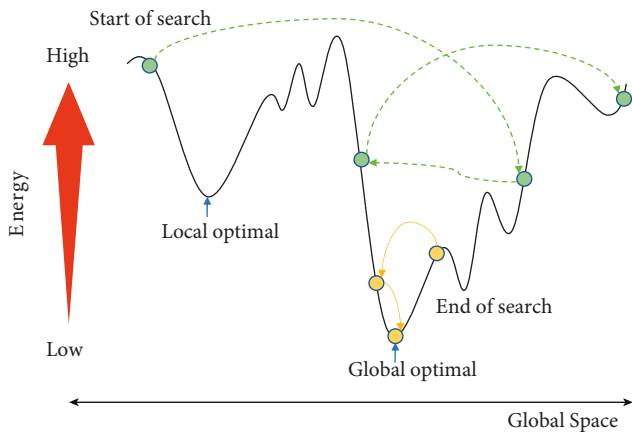


FIGURE 5: Principle of the simulated annealing algorithm.

TABLE 1: Comparison between metal object and optimization problem.

Metal object	Optimization problem
Dissolution process	Set temperature
Energy	Objective function
Cooling	Decrease in control parameters
Particle state	Solution
Minimum energy state	Optimal solution

current temperature $T_i = T_1$, and determine the chain length for each number of iterations L .

- (2) A real number encoding form is used for the search of the domain. The search is carried out within the limits of the design in combination with constraints such as step size, range, demand, and capacity (Figure 7).

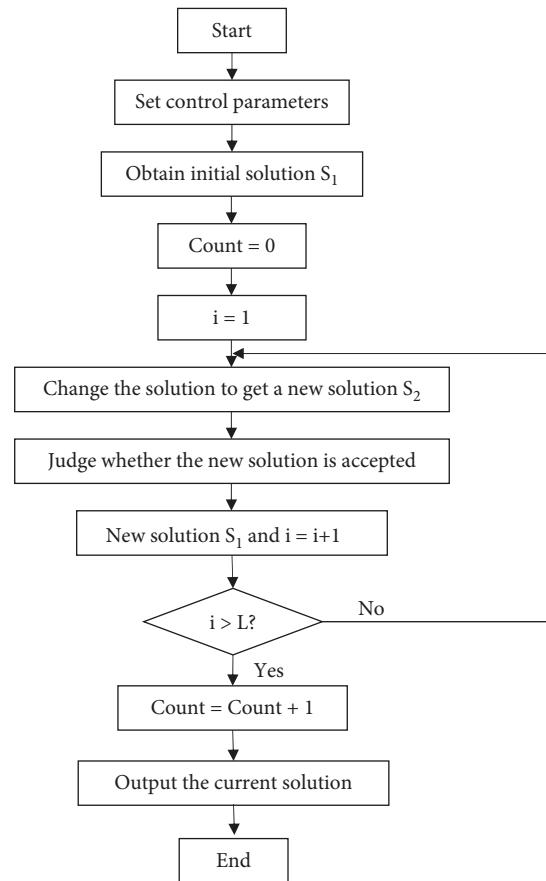


FIGURE 6: Solution process of the simulated annealing algorithm.

- (3) Calculate the acceptance probability of S_j , and determine whether the acceptance probability is greater than (0, 1) randomly generated uniformly distributed

random numbers on the interval. If the acceptance probability is larger, then S_j is selected as the new path.

- (4) Terminate the algorithm if it is satisfied that the new solution S_j is not accepted in several Metropolis chains or set the end temperature; otherwise, decay T by the decay function and return to the second step.

3. Characteristic of Simulated Annealing Algorithm

There are a number of multiobjective, nonlinear, and complex combinatorial optimization problems that are difficult to solve effectively by traditional exact algorithms, which require the use of artificial intelligence optimization algorithms. As one of these algorithms, the simulated annealing algorithm is based on the solid annealing principle and simulates the annealing process, making the whole process simpler and more flexible, while producing efficient results.

Firstly, the solution to the simulated annealing algorithm is derived by setting the relevant parameters appropriately. The speed and quality of the solution can be directly affected by the different parameter settings, so the solution to the combinatorial optimization problem can be improved by modifying the values of the parameter settings. It can be seen that the simulated annealing algorithm has the flexibility to set the parameters according to the differences in functions and variables in the problem when solving different optimization problems. The simulated annealing algorithm is therefore more flexible than other artificial intelligence algorithms. In addition, the simulated annealing algorithm has a fast convergence rate, so that VPP can be solved in a short time. Improvements and optimizations over the years have allowed it to perform global searches in addition to local search capabilities, while remaining fast and efficient compared with other algorithms. Moreover, for realistic combinatorial optimization problems that need to be solved, the simulated annealing algorithm can be easily used to produce satisfactory solutions by using computer-related software programmes. At the same time, it has general applicability to other similar problems.

The above description shows that the simulated annealing algorithm has certain advantages over some other artificial intelligence optimization algorithms for solving large-scale vehicle path problems. However, there are still some shortcomings in its specific solution process, especially in the setting of parameters. The main objective of the warming process is to reach an initial value temperature, which is then cooled down according to the corresponding temperature update function. In this process, two aspects are usually encountered. The first one is that the initial temperature is high and the cooling rate is slow, in which case the search space is relatively large and it is easy to obtain the global optimal solution, but then there is the problem of too much work and too much time spent. In the isothermal process, it is often necessary to go through several iterations of the inner loop to reach a certain temperature equilibrium,

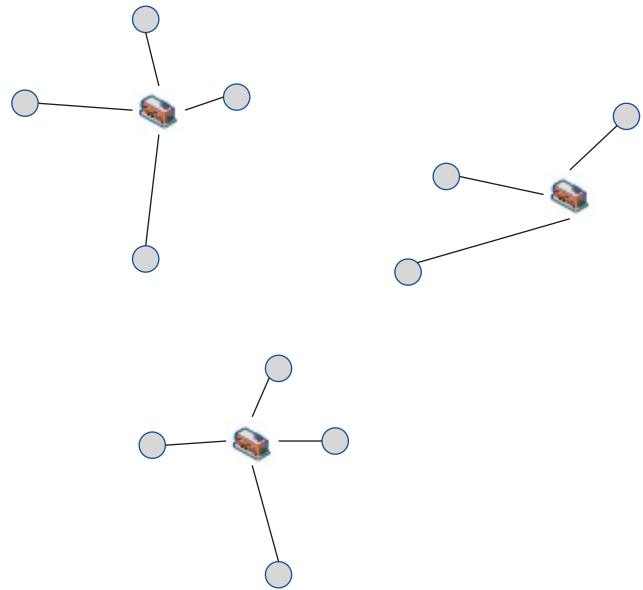


FIGURE 7: Distribution center identification and neighborhood search.

which can lead to the loss of the current optimal solution due to the probability of accepting a new solution. This results in a larger search space, which in turn increases the search time and makes it inefficient. Secondly, the initial temperature is low and the cooling speed is fast; in this case, the search space is relatively small, although the speed is fast, often do not obtain the global optimal solution, but the local optimal solution. In the isothermal process, it is often necessary to go through several iterations of the inner loop to reach a certain temperature equilibrium, which can lead to the loss of the current optimal solution due to the probability of accepting a new solution. This results in a larger search space, which in turn increases the search time and makes it inefficient.

In the cooling process, the simulated annealing algorithm needs to be slow enough to achieve an equilibrium state at all temperatures. In this case, the speed of the solution decreases significantly, and although a satisfactory solution is eventually obtained, the advantages of the algorithm over other algorithms are not reflected. If the speed is pursued, there is a risk that the resulting solution is not globally optimal, which requires a balance between speed and quality to achieve a satisfactory solution.

4. Conclusion

In recent years, along with the rapid development of Internet technology and e-commerce, the logistics industry has been in a state of booming development. At the same time, it also has certain problems, especially logistics costs have been high, seriously affecting the economic efficiency of enterprises and the service experience of customers. Among the logistics costs of enterprises, transport costs account for the highest proportion, so the issue of vehicle paths has become the focus of current scholarly research. Rational planning of logistics distribution paths can help improve the economic

efficiency of transport enterprises and give better customer satisfaction.

Firstly, this study summarizes the concepts related to urban logistics systems, vehicle path problems, and algorithms for solving vehicle path problems through reading and collating a large amount of literature and adds consideration to the problem of uncertainty in road conditions in response to some of the shortcomings in current research on vehicle path problems. Then, this paper analyzes and summarizes the urban logistics distribution path optimization problem based on the research of scholars at home and abroad and constructs the path optimization model in the logistics distribution process using the simulated annealing algorithm. Finally, the problems of the simulated annealing algorithm are addressed in terms of both advantages and disadvantages.

Due to the time and data limitations of the study, there are a number of areas that need further refinement in this study. This paper addresses the path problem of distribution from the distribution center to the sales department, with the shortest driving distance as the goal; the goods must be delivered within the time window specified by each sales department. And the cost and customer needs need to be considered in the distribution process for customer service, use it in the soft time window, increase the penalty cost at the same time, and finally achieve the overall goal of reducing the distribution cost.

Data Availability

The labeled datasets used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

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