Research on Picking Route Optimization Based on Simulated Annealing Algorithm

Danyi Zhang\textsuperscript{1, a}, Ji Zhang\textsuperscript{2, b}

\textsuperscript{1}School of Energy Science and Engineering, Henan Polytechnic University Jiaozuo, China
\textsuperscript{2}School of Energy Science and Engineering, Henan Polytechnic University Jiaozuo, China
\textsuperscript{a}e-mail: 2947089713@qq.com, \textsuperscript{b}e-mail: 1271820238@qq.com

Abstract. This paper aims to optimize the low efficiency of picking operations in the distribution center at present stage, and to study the problem of outbound picking routes in the same-end in-out automated warehouse. Aiming at the traditional NP difficult-to-solve algorithm, in order to solve the limitations of the accuracy and scale of the existing algorithm, this paper takes a certain outbound task of the Baidie distribution center as an example, which uses the simulated annealing algorithm to optimize the picking path. In addition, the optimization results are compared with the results of the nearest-neighbor heuristic and the nearest-insertion heuristic. The results show that, compared with the nearest-neighbor heuristic and the nearest-insertion heuristic, the path distance of the algorithm designed in this paper is reduced by 25% and 16.67% respectively, which has a significant improvement.

1. Introduction

With the continuous expansion and deepening of modern production scale, warehouse has become the key link that determines the efficient operation of logistics system. Because the automated three-dimensional warehouse has the advantages of large cargo storage capacity, small floor space, simple mechanization and automatic management, it can reduce labor intensity, improve the efficiency of warehouse operation, and accelerate the turnover of goods. It has been generally recognized and widely promoted in the industry. However, due to the late start of the development of automated three-dimensional warehouse and its slow development, most scholars focus on the research of hardware equipment, automatic control and communication technology of automated three-dimensional warehouse, trying to strengthen the safety of operation and reduce the rate of damage to improve the quality of service. However, there are few studies on the scheduling management and operation optimization of automated warehouses. Therefore, the optimization of the picking path that determines the efficiency of the automated warehouse has gradually become a hot and difficult research point. Like the traveling salesman problem, the picking problem of the fixed shelf is also complicated and NP hard, so it is difficult to find the optimal solution. The nearest neighbor method as the simplest TSP heuristic algorithm to solve such problems is the easiest way [1]. But when the cargo locations are scattered, the algorithm is prone to large errors. After Liu Zengxiao and other scholars analyzed that it is not the optimal algorithm, they proposed the loop structure operation path method [2]. According to the characteristics of the fixed shelf, they constructed a picking path composed of a loop structure without intersections. This path can reduce the operating time of the system to some extent. The optimization
results of this algorithm are better than the nearest neighbor method. However, this algorithm stratifies the shelves during the process of picking goods, which makes the stacker need to travel multiple loops to complete the picking task, resulting in an increase in the moving distance of the stacker. In order to overcome the shortcomings of multiple loops that increase the picking path, Jiang Lilin and Zhang Chi constructed all the picking locations as a closed-loop operation path, and used graph theory to optimize the path [3]. All cargo locations can be gathered on the same map, and any two cargo locations can be connected to each other. This algorithm is suitable for picking less than 15 cargo positions. Although the result is better than traditional algorithm optimization, it can only find one feasible solution at a time, which cannot meet the diversified needs of today's warehouse with large orders and large turnover. Accordingly, the genetic algorithm evolved from the genetic mechanism of simulating the survival of the fittest and the survival of the fittest in the natural environment, as a probabilistic search algorithm for adaptive global optimization, has been widely used in various fields to solve large-scale problems. Scholar Zhou Chao took a company as an example to establish a picking route optimization model, and then used genetic algorithm to solve the model [4]. Thus, he designed a set of good picking operations for a three-dimensional warehouse. However, in terms of the solution accuracy, the local search ability of genetic algorithm is poor, the convergence speed is slow, and it is easy to be premature. In view of the current problems of low accuracy in solving, the algorithm design should follow the principles of simple process, general purpose, strong robustness, parallel processing, and suitable for solving complex nonlinear optimization problems. The simulated annealing algorithm that simulates the annealing process in thermodynamics has significant advantages in this respect, so this paper intends to use the simulated annealing algorithm to search for the optimal picking path of the stacker.

2. Algorithm design of picking route based on simulated annealing

The simulated annealing algorithm was first proposed by Metropolis et al., and it involved probability [5]. The annealing process of the solid matter in physics is to raise the temperature of the solid to a high enough temperature. The particles in the solid will move violently when encountering high temperature, causing the arrangement to change. The internal structure becomes disordered, and the internal energy increases. Then with the temperature drop, that is, the cooling process, the internal energy of the particles decreases. At each temperature, the particles reach equilibrium. The thermal motion of the particles is gradually weakening, and the energy is very low at room temperature.

According to the Metropolis criterion, the probability of a particle approaching equilibrium at temperature T is exp(-ΔE/(kT)), the internal energy at temperature T is E, the temperature change is ΔE, and k is Boltzmann's constant[6].

The core idea of the simulated annealing algorithm is to select a solution randomly as the initial solution, and it can produce a different solution by transforming randomly. If there is a better solution than the last solution, the new solution must be accepted. If the new solution differentiates too much from the original solution, it will be accepted according to the certain probability. And this probability decreases over time. The calculation of "a certain probability" here refers to the annealing process of metal smelting, which is also the origin of the name of the simulated annealing algorithm.

(1) Initialization: initial temperature T (sufficiently large), initial solution state S (the starting point of the algorithm iteration), the number of iterations L.
(2) Take steps (3) to (6) for k=1,…., L.
(3) Generate a new solution S'.
(4) Calculate the increment
\[ Δt' = C(S') - C(S) \] (1)
C(S) is the evaluation function.
(5) If Δt'<0, accept S'as the new current solution, otherwise accept S' as the new current solution with the probability exp(-Δt'/T).
(6) If the termination condition is met, the current solution is output as the optimal solution, and the program ends.
(7) T decreases gradually, then go to step 2.
The process of simulated annealing algorithm to generate and accept new solutions mainly consists of five steps:

First, make the initial solution generate a picking sequence, and replace or exchange the elements in the picking sequence, so that new picking sequences can be continuously obtained.

The second is to calculate the difference between the objective function corresponding to the current picking method and the new picking method. Through a certain transformation, the difference of the objective function appears. The calculation of the difference is usually expressed as an increment.

The resulting new solution is then judged by the acceptance criteria Metropolis. If $\Delta t' < 0$, the solution is accepted as the new current solution, if $\Delta t' > 0$, the solution is accepted as the new current solution at the probability of $\exp(-\Delta t'/T)$.

Finally, if the new solution is accepted, the solution continues to be generated. The changed part of the current picking sequence is replaced, and the objective function value of the newly generated solution at this time is determined. This is how the current solution completes the first iteration.

With the first iteration, the next experiment can be performed. If the new solution is abandoned, just continue to iterate on the original current solution. The solution obtained by the simulated annealing algorithm is not related to the initial solution.

3. Optimization of picking path based on simulated annealing algorithm

According to the specific analysis of the status quo of Baidie Logistics Center, there is currently a batch of goods waiting to be delivered. The computer system generates an outbound order based on the order information and then sends a pick-up command to the stacker. There are 12 different goods positions that need to be selected on the delivery list. The code of the goods position corresponds to the code of the goods to be selected. Set the position of the first cargo compartment as the starting position of the stacker. The coordinate of the cargo position is expressed as $(x, y)$, with “$x$” as column and “$y$” as layer. The stacker returns to its original position after all goods have been sorted. The cargo location code is as follows:

![Flow chart of simulated annealing algorithm](image)
Table 1. The cargo Coding Table

| Numbering | coordinates (x,y) | Numbering | coordinates (x,y) |
|-----------|-----------------|-----------|-----------------|
| 1         | (1,2)           | 7         | (5,7)           |
| 2         | (1,6)           | 8         | (7,3)           |
| 3         | (3,4)           | 9         | (7,8)           |
| 4         | (3,7)           | 10        | (8,5)           |
| 5         | (5,1)           | 11        | (8,6)           |
| 6         | (5,4)           | 12        | (10,3)          |

Figure 2. Location map of the goods

Relative distance calculation of nodes:
Use \( V_i \) (\( i=1,2,3,...,12 \)) to represent goods 1 to 12, respectively, and calculate the relative distance of each node, using the following distance formula:

\[
d_{ij} = |x_i - x_j| \times L + |y_j - y_i| \times H
\]

(2)

\( d_{ij} \): the distance between two cargo boxes;
\( x_i \): the horizontal axis coordinate of the cargo grid;
\( y_j \): the vertical axis coordinate of the cargo grid;
\( L \): Length of cargo compartment (m);
\( H \): Height of cargo compartment (m).

Table 2. Table of relative distances between nodes

| Node 1 | Node 2 | Node 3 | Node 4 | Node 5 | Node 6 | Node 7 | Node 8 | Node 9 | Node 10 | Node 11 | Node 12 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Y1     | Y2     | Y3     | Y4     | Y5     | Y6     | Y7     | Y8     | Y9     | Y10    | Y11    | Y12    |
| \( - \) | \( 21 \) | \( 26 \) | \( 43 \) | \( 10 \) | \( 15 \) | \( 20 \) | \( 25 \) | \( 30 \) | \( 35 \) | \( 40 \) | \( 45 \) |
| \( - \) | \( 21 \) | \( 26 \) | \( 43 \) | \( 10 \) | \( 15 \) | \( 20 \) | \( 25 \) | \( 30 \) | \( 35 \) | \( 40 \) | \( 45 \) |
| \( - \) | \( - \) | \( 41 \) | \( 17 \) | \( 3 \)  | \( 8 \)  | \( 13 \) | \( 18 \) | \( 23 \) | \( 28 \) | \( 33 \) | \( 38 \) |
| \( - \) | \( - \) | \( - \) | \( 46 \) | \( 8 \)  | \( 13 \) | \( 18 \) | \( 23 \) | \( 28 \) | \( 33 \) | \( 38 \) | \( - \)  |

Establish a simulated annealing algorithm model for solving the picking route:

(1) Solution space
All the paths that the stacker picks all the cargo positions and returns to the initial position form the solution space, which contains all the arrangement of the positions of \( \{1,2,\ldots,n\} \). Each cargo position in the solution space \( S \) can be expressed as \( (K1, K2, \ldots, Kn) \), and also denote \( Kn+1=K1 \). The initial solution of the problem can be selected as \( (1,2,\ldots, N) \).

(2) Objective function
The objective function here is the length of the path that the stacker picks up all the positions and returns to the first position. It can also be called the cost function. The purpose is to obtain the minimum value of the objective function.

(3) Generate new solutions

The following two methods can be used to generate a new solution:

The first is to choose two different numbers i and j between 1 and n, and exchange the access sequence between i and j.

The transformation is: \((K_1,K_2,\ldots,K_i,\ldots,K_j,\ldots,K_n)\) becomes \((K_1,K_2,\ldots,K_{i-1},K_j,K_{j-1},\ldots,K_{i+1},K_i,K_{j+1},\ldots,K_n)\).

(4) Temperature management

The most important problem in simulated annealing algorithm is temperature management. The initial value of the temperature is one of the important factors affecting the global search performance of the simulated annealing algorithm. The higher the initial temperature is, the more likely to find the global optimal solution. However, it takes a lot of time to calculate. On the contrary, it can save calculation time, but the global search performance may be affected. In the actual application process, the initial temperature needs to be adjusted several times based on the experimental results.

In addition, the decay function of temperature must be selected. The decay function is used to control the annealing speed of the temperature. In order to simplify the calculation, the general use of cooling way is

\[ T(t+1) = kT(t) \quad (3) \]

Where "t" represents the number of temperature drops, "k" is a constant slightly less than 1 and is positive.

4. Experimental results

Parameter setting: 12 positions to be picked, initial temperature: 500, ending temperature: 0.0001, cooling rate: 0.98.

![Optimal path diagram](image)
The shortest distance obtained by using simulated annealing algorithm is 32.4m.
The shortest route obtained by using the simulated annealing algorithm: 1 2 4 7 9 11 10 12 8 5 6 3 1.

Table.3  Comparison Table Of optimization results of three sorting methods

| optimization method          | Walking distance (m) | Reduced distance (m) compared to the nearest point method | The ratio of distance reduction compared to the nearest approach method |
|------------------------------|----------------------|-----------------------------------------------------------|---------------------------------------------------------------------|
| nearest-neighbor heuristic   | 43.2                 | 0                                                         | 0                                                                   |
| nearest-insertion heuristic  | 36                   | 7.2                                                       | 16.67%                                                              |
| Simulated annealing algorithm| 32.4                 | 10.8                                                      | 25%                                                                 |

5. conclusion
From the above table, it can be seen that compared with the nearest approach method and the nearest insertion method, the simulated annealing algorithm can effectively shorten the moving distance of the stacker for picking operations. For Baidie Logistics Center, the picking time is greatly reduced each time, so that it can respond well to the development trend of orders with diverse varieties and small demand. It not only improves the efficiency of picking operations, but also improves the overall operation efficiency and customer service level of Baidie Distribution Center. Therefore, research shows that the picking path designed by the simulated annealing algorithm significantly improves the picking efficiency of the distribution center.

Acknowledgment
This work was supported by the National Natural Science Foundation of China (No. 61803147), in part by the Key Scientific and Technological Project of Henan Province (No. 182102310799), and in part by the Foundation of Henan Educational Committee (No.18A580003).

References
[1] Shao,X.J.,Yin,C.H. (2013)Research on Online Shopping Delivery Route Optimization Based on Shortest Path Method and Nearest Insertion Method. Logistics Engineering and Management,35(01):109-112.
[2] Liu,Z.X, Feng,Z.Y. Wu, J. Chang,F.L. (2006) Simple optimization algorithm for the operation path
of the sorting automated warehouse stacker. Hoisting and Conveying Machinery.

[3] Jiang, L.L., Zhang, C. (2010) Optimization of Picking Path of Automated Warehouse Stacker Based on Graph Theory. Logistics Technology, 33(07):97-99.

[4] Zhou C. (2013) Research on optimization of storage location and picking route of enterprise three-dimensional warehouse. Anhui University of Technology, Anhui.

[5] Li, H.L., Wang, Z.H., Wang, J.W. (2016) Application of Genetic Optimization Algorithm Based on Simulated Annealing in TSP Problem. Heat Treatment Technology and Equipment, (06): 51-55.

[6] Song, Y.Z. (2013) Application of heuristic algorithm based on simulated annealing algorithm in VRP. Central China Normal University, Beijing.