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BUILDING MATERIALS LOGISTICS ROUTE OPTIMIZATION UNDER LOW-CARBON ECONOMY-BASED ON SIMULATED ANNEALING

[1]HUI LI, [1]JINGXIAO ZHANG, [2]ZHEN SHI

[1]School of Civil Engineering, Chang'an University, Xi'an Shaanxi, 710061, China
[2]School of Geology Engineering and Geomatics, Chang'an University, Xi'an, Shaanxi,710054, China

ABSTRACT

Since the logistics is an industry with relatively higher energy consumption, the building industry low-carbon logistics ought to attract wide attentions from the building enterprises. Simulated annealing is an effective intelligent algorithm for optimizing the building materials logistics route. This paper analyzes the similarities between the process of the building materials logistics route optimization and the process of simulated annealing, applies the simulated annealing to the adaptability of the building materials logistics route optimization, and gets the results that simulated annealing can be used to solve this issue. Finally, this paper applies the simulated annealing in optimizing the building material performance so as to control and optimize the building materials performance.

Keywords: *Low-Carbon Economy, Building Materials, Logistics, Logistics Route, Simulated Annealing*

1. INTRODUCTION

The rise of low-carbon logistics in the building industry under low-carbon economy first attributes to low-carbon revolution and official advocacy of green and environmental protection at the Copenhagen Climate Change Conference. With the increasingly severe climatic issues, globalized "low-carbon economy" is on the rise, human beings will therefore step into the new low-carbon era, namely, a brand new era based on "low energy consumption, low pollution, low emission". Since the building industry logistics is an industry with relatively higher energy consumption, the building industry low-carbon logistics ought to attract wide attentions from the building enterprises. As the development of high-end service industry, building industry logistics shall walk on the low-carbon path, and focus on developing green logistics services, low-carbon logistics and intelligent information. Building industry logistics information and intelligence are essential requirements to develop modern logistics service industry as well as effective method to serve low-carbon society. Intelligent logistics service is capable of further reducing the impacts of building materials logistics service on ecological environment. Therefore, information is not only the basis of modern logistics but also the precondition of improving logistics efficiency. It is necessary to further develop and apply intelligent tools, build the logistics information platform for the building industry, and realize the building materials logistics route optimization under low-carbon economy.

2. SIMULATED ANNEALING ALGORITHM

Simulated annealing (SA) is a simulated intelligent algorithm basic on the principle of solid annealing [3]. It roots from the enlightenment of annealing process in physics and simulates the physical process of heating, isothermal status and cooling, and is a heuristic stochastic optimization algorithm integrating Metropolis sampling principle.

a. Compared to local search algorithm, the simulated annealing is expected to obtain the optimal approximation in a short period.

b. The simulated annealing allows random selection of initial solution and random number sequence, and obtain the optimal approximation. Therefore, this optimization algorithm has reduced preparatory works.

c. The simulated annealing can be applied to various issues of building materials logistics route optimization, and this program can be effectively applied to other issues solution.

The motion of ball A in the curve of energy function is similar to physical annealing process, as shown in figure 1. So, we represent the intelligent calculation process of optimization with the motion of ball A[4]. There are two minimum points in the

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curve of energy function, A and B. A is a partial minimum point while B is the minimum point of the whole. If we place a ball (symbolizing the original status of system) on the upper left of point A as shown in the figure to symbolize original status, by changing the status of system, the minimum point A will necessarily be reached. If we introduce noise to system to create vibration in the whole system, there is the possibility that the ball will be moved to the position near B from A[5]. To make ball A reach minimum value point B, it is better to make the system vibrate violently first to make the ball deviate, and then shake softly to make the ball gradually get close to B, so that we can acquire the global minimum of energy function.

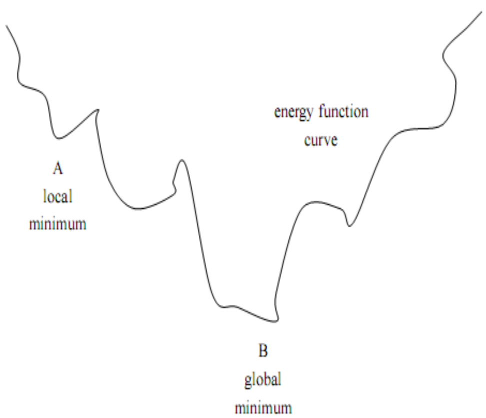

Figure 1: Sketch Map Of Optimal Solution Similar To Physical Annealing

In fact, the three main components of algorithm are acceptance criteria, random-number generator (namely Metropolis algorithm), cooling schedule, new-solution generator and field structure. The process of solid's reaching to thermal equilibrium in constant temperature can be simulated by Monte Carlo method. Therefore, Metropolis et al pointed out importance sampling method in 1953, namely accepting new status with probability[6]. Giving the original status i represented by the relative position of particle as the current status of solid, the energy of this status is E_i, and then we give a random slight change to the displacement of some random particle by perturbation facility to acquire a new status j whose energy is E_j. If $E_j \prec E_i$, the new status j is accepted as current status; otherwise, with the consideration to the influence of thermal motion, whether the new status will be accepted should be judged by the probability of this status. The probability of going to equilibrium in temperature T is:

$$p_r = \exp(-\frac{\Delta E}{kT}) \qquad (1)$$

In which, E is the internal energy in temperature T ; ΔE is the change, k being Boltzmann constant. p_r is the value smaller than 1. Create an even random number ξ within the interval [0， 1] with random number generator; if $p_r \succ \xi$, new status j will be accepted, otherwise, rejected. If new status j may be accepted, replace i with j as current status and repeat the above process. After transferring in large amount (the transformation of solid status is called transferring), the system tend to reach equilibrium status of lower energy. Simulate a combination optimization matter by solid annealing. After simulating internal energy E into target function value f and temperature T evolves to control parameter t , we can gain the simulated annealing algorithm to solve the matter of combination optimization. Starting from initial solution i and initial value of control parameter t , repeat the iteration of "new solution generation→ calculating difference of target function → acceptance or rejection" to current solution, gradually attenuate t value. When algorithm terminates, current solution is the approximate optimal solution. This is a kind of heuristic random seeking process basic on Monte Carlo iterative method. The acceptance probability from i to j is determined by the following Metropolis criteria.

$$P(t_k) = P(i \Rightarrow j) = \begin{cases} 1 & f(j) \le f(i) \\ \exp(\frac{f(i) - f(j)}{t_k}) & f(j) > f(i) \end{cases} \qquad (2)$$

After large amount of transferring, the system goes to the equilibrium state of lower energy and the probability of each status tends to be some kind of probability distribution[7]. When the temperature goes to zero, the new status with higher energy than current status cannot be accepted. This is Metropolis criteria which has significantly less calculation than Monte Carlo method and is an effective leading sampling method. By reducing the value of control parameter T and repeatedly carrying out Metropolis algorithm, we can finally acquire the integral optimal solution of combination optimization when control parameter T goes to zero. We call the series of important parameters to control simulated annealing as cool schedule. A cooling schedule

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should regulate the following parameters: a. T_0 , the initial value of control parameter t ; b.decay function of control parameter t ; c. length of Markov-chain, L_k (namely the times of iteration required to reach to quasi-equilibrium distribution in every random travel process, namely the position of a local convergence solution); d. choice of termination conditions. Neighborhood structure is in fact a mapping, for example, supposing (S, f) is an example of combination optimization, a neighborhood structure is a mapping, $N : S \to 2^S$. Its meaning is that for every solution $i \in S$, there is a set of solution $S_i \subset S$ and these solutions are "near" i in a sense. The set S_i is called as the neighborhood of i and every $j \in S_i$ is called as a near-solution. Besides, it is assumed $j \in S_i \Leftrightarrow i \in S_j$. New solution generator can be interpreted as: supposing (S, f) is an example of combination optimization while N is a neighborhood structure, namely a generator selects one method of solution j from the neighborhood S_i of solution i .

3. DESCRIPTION OF SIMULATED ANNEALING AND ITS STRUCTURE

Simulated annealing algorithm can be described as: supposing all possible statuses of system are $V = \{v_1, v_2, ..., v_N\}$ and there is one related energy E which is the function of status, namely $E(v)$ [8]. Supposing control parameter is temperature T , our goal is to locate one system status v^* to make $E(v^*) = \min(v_i, v_i \in V)$. The thought of simulated annealing is that T is made to decline from a sufficiently high value. For every T , simulate the thermal equilibrium status of system under T by Metropolis sampling method, namely creating a new status v_j through random disturbance. Calculate the increased energy of system $\Delta E = E(v_j) - E(v_i)$ and accept v_j as current status with probability $e^{(-\Delta E / kT)}$.

The description of simulated annealing algorithm is as follow:

(1) initialization: given a random intitial status V_0 , $V_1 = V_0$; calculate $E(v_0)$ and set intitial temperature value for parameter T .

(2) create a random disturbance Δv , calculate $\Delta E = E(v_i + \Delta v) - E(v_i)$.

(3) If $\Delta E \prec 0$, move to 5), otherwise, create an even random number ξ within the interval (0, 1).

(4) If $e^{-\Delta E / KT} \le \xi$, move to 2).

(5) Replace v_i with $v_i + \Delta v$, and let $E = E + \Delta E$.

(6) Test whether the system is stable under T . If not, move to 2).

(7) Acquire $T^{'} \prec T$ and let $T = T^{'}$.

(8) Whether annealing is basically over, if so, stop; if not move to 2).

In a word, the strategy of simulated annealing algorithm is: start to explore the whole solution space from a random initial solution and create s new solution by disturbance, and then adopt Metropolis criteria to judge whether the new solution should be accepted and lower down temperature. The flow of simulate annealing is shown in figure 2.

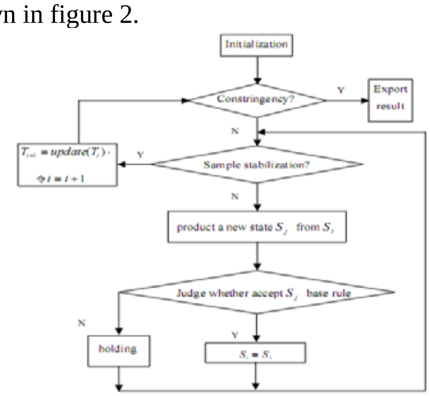

Figure 2: Micro Image Of Dividing Rule

4. THE SIMILARITIES BETWEEN BUILDING MATERIALS LOGISTICS ROUTE OPTIMIZATION AND PHYSICAL ANNEALING UNDER LOW-CARBON ECONOMY

There are similarities between building materials logistics route optimization and physical annealing process of crystalline substances though the simulated annealing. As for the issue of building materials logistics route optimization, there is also a similar process, each point of building materials logistics route optimization in the solution space represents a solution of different targeted functions. The so-called optimization is a process to find the functions' minimal solution in the solution space. If function is deemed as the energy function, control parameters as temperature, the solution space as the state space, then the simulated annealing (SA)

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finding the ground state is an optimization process to obtain the minimum of the objective function. Therefore, there are similarities between optimization process and physical annealing process based on the Metropolis acceptance criterion. The similarities between the building materials logistics route optimization and physical annealing are listed in Table 1 below.

Table 1: The Similarities Between The Building Materials Logistics Route Optimization And Physical Annealing

Building Materials Logistics Route Optimization	Physical Annealing	Building Materials Logistics Route Optimization	Physical Annealing
Solution	Particle State	Metropolis Sampling Process	Constant Temperature Process
Optimal Solution	Lowest Energy State	Drop of Control Parameter	Cooling
Set the Initial Temperature	Melting Process	Objective Function	Energy

5. ADAPTABILITY OF APPLYING SIMULATED ANNEALING TO THE ISSUE OF BUILDING MATERIALS LOGISTICS ROUTE OPTIMIZATION

There are many building materials issues to be optimized. The building materials logistics optimization under low-carbon economy satisfies the application requirements of simulated annealing. The basic form applied by simulated annealing is to start from the selected initial solution, produce a series of Markov chain with the help of decreasing control parameter t, make use of new solution generating devices and acceptance criterion (the Metropolis acceptance criterion), repeatedly conduct the test of four tasks "generating a new solution—calculate the objective function—identify whether to accept the new solution—accept (abandon) the new solution", constantly iterate the current solution, and achieve the execution process of objective function optimization. Therefore, the algorithm application shall meet the below three requirements: (1) description of the issues' concise forms, namely, the mathematical model. (2) new solution generation and the acceptance criterion. (3) cooling schedule.

1. description of the issues' concise forms, namely, the mathematical model, is made up of solution space, objective function and initial solution.

a. Solution space of logistics optimization . It is the set of all possible solutions of logistics optimization issues, and constrains the range of initial solution selection and new solution. As for unconstrained optimization issues, any possible solution is a feasible solution, so the solution space is set of all feasible solutions; among many portfolio optimization, a solution shall not only satisfy the requirement of objective function optimum, but also meet a group of constraints, so the solution set might include some infeasible solutions. In light of this, solution space can be constrained to the set of all feasible solutions, that is, take solution constraints into consideration in generating solutions; it is also permissive for solution space to include infeasible solution, and add the so-called penalty function into the objective function so as to penalize the appearance of infeasible solutions.

b. Objective function of logistics optimization . Objective function is the mathematical description of the logistics optimization's optimal object, which is the sum form of several optimal objects. The selection of objective functions must correctly show the requirements for issues' overall optimization. For instance, as mentioned above, when solution space includes infeasible solutions, the objective function shall also include the penalty functions of infeasible solutions, and transform a constrained optimal issue into a unconstrained optimal issue. In general, the value of objective function is not necessarily the issue's optimal objective value, but its corresponding relation shall be evident. In addition, the objective function expression shall be easy to calculate, so that provide favorable conditions for simplifying the calculation of objective functions difference in the optimal process to improve the algorithm efficiency

c. Initial solution of logistics optimization. Initial solution is the starting point of algorithm iteration. The selection of initial algorithm shall make the algorithm export high-quality final solution, but a lot of experimental results show that the annealing algorithm is a robust algorithm, namely, the algorithm's final solution has little dependence on the initial solution.

2. Generation of new logistics optimization solution and the acceptance criterion

a. Calculation of logistics optimization and the objective functions difference accompanied by the new solution. Since the objective functions difference is generated from the transformation part, it is recommended that the objective functions difference is calculated by the increment.

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b. Identify whether the new logistics optimization solution is accepted. Identified evidence is the Metropolis criterion. In addition, among the constrained portfolio optimal issues, this acceptance criterion shall be added with feasibility identification of the new solution.

c. When the new logistics optimization solution is accepted, replace new solution with the current solution, and revise the objective function value in the meantime. At this time, the current solution realizes one iteration, so the next round of test can be started on this basis. When the new solution is identified to be abandoned, continue the next round of test based on the original current logistics optimization solution.

3. Logistics optimization cooling schedule

It is the set of a group parameters in the control algorithm process, consisting of control parameter initial value and its decay function. The length of stopping criterion of corresponding Markov chain (all iterated process to each time value of T) are key to the application of simulated annealing. In the computer debugging process, the parameter values are required to be revised constantly to seek the global optimal solution.

Therefore, the issue of building materials logistics route optimization under low-carbon economy can be obtained with the application of simulated annealing.

6. CASE ANALYSIS: EFFICIENCY OF BUILDING ENERGY-SAVING

There are many issues to be optimized in the building materials. Many matters in building energy-saving need optimizing. Wit the transport of energy-saving materials as an example, this paper illuminates the application of simulated annealing inn building energy-saving[9].

6.1 Mathematical Model of Efficiency of Building Energy-saving

The matter of building energy-saving can be described as: supposing there are n operation points, they are represented by $1,\dots,n$. The distance between operation point i and j is $d(i,j)i,j=1,\dots,n$. TSP matter is to seek for one loop the transport of materials only passes once and the total length of route is the shortest. Key factors:

a. solution space: solution space S is all the loops through which every city is only visited once. It is the set of all circular permutation within $\{1,\dots,n\}$. Members of S are marked as $(p_1,p_2,\dots,p_n)$, $p_n+1=p_1$. Original solution can be chosen as $(1,\dots,n)$.

b. Target function. It is the total length of all routes or can be called as cost function. We need to acquire its minimum value which is $Min\, f(p_1,p_2,\dots,p_n)=\sum_{i=1}^{n} dp_i p_{i+1}$, $p_{n+1}=p_1$.

c. New solution can be generated respectively through or alternatively usage of 2 transformation method and 3 transformation method.

Hereinafter referred to the sequence of energy-saving building's construction site as $p[u]$, meaning the visited energy-saving building's construction site, where u is the sequence, meaning sequence of the visited energy-saving building's construction site, $c[0],c[1],\dots,c[5]$ means the flexible array member of the energy-saving building's construction site correspondent to generate( ) in the below functions.

The so-called 2 transformation method is to randomly select two sequences of u , u , reverse the visiting sequences of these two sequences and all sequences of energy-saving building's construction site during the time. For instance, the original visiting sequences are listed as below:

$$\dots p[u-1]\,p[u]\,p[u+1]\dots p[v-1]\,p[v]\,p[v+1]\dots$$

$$c[0]\quad c[1]\quad c[2]\qquad c[3]\quad c[4]\quad c[5]$$

Select sequences of u and v , and $u \prec v$. The 2 transformation method is to reverse the sequences of $p[u]$ and $p[v]$ and in-between all sequences of energy-saving building's construction site so as to generate new solution:

$$\dots p[u-1]\,p[v]\,p[v-1]\dots p[u+1]\,p[u]\,p[v+1]\dots$$

$$c[0]\quad c[4]\quad c[3]\qquad c[2]\quad c[1]\quad c[5]$$

The so-called 3 transformation method is to randomly select three sequences $u \prec v \prec w$, move sequences of u and v as well as in-between all sequences of energy-saving building's construction site behind the energy-saving building's construction site $p[w]$ with sequence of w .

For instance, the original visiting sequences are listed as below:

$$\dots p[u-1]\,|\,p[u]\dots p[v]\,|\,p[v+1]\dots p[w]\,|\,p[w+1]\dots$$

$$c[0]\quad c[1]\quad c[2]\quad c[3]\quad c[4]\quad c[5]$$

3 Post the transformation method

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$$\ldots p[u-1] \| p[v+1] \ldots p[w] \| p[u] \ldots p[v] \| p[w+1] \ldots$$

$$c[0] \quad c[3] \quad c[4] \quad c[1] \quad c[2] \quad c[5]$$

d. Cost function difference

Cost function difference accompanied by the new solution can be respectively calculated through the below formulas.

As for 2 transformation $(r=2)$,

$$\Delta f = (d_{p_{u-1}p_v} + d_{p_u p_{v+1}}) - (d_{p_{u-1}p_u} + d_{p_v p_{v-1}})$$

As for 3 transformation (r=3)

$$\Delta f = (d_{p_{u-1}p_{v+1}} + d_{p_w p_u} + d_{p_v p_{w+1}}) - (d_{p_{u-1}p_u} + d_{p_v p_{v+1}} + d_{p_w p_{w+1}})$$

6.2 Model Evaluation and Analysis

Here, we select a group of coordinates of operation points to put them into experiment. The result of simulation is as follow:

[90 80 85 65 25 41 37 54 25 7
40 55 84 75 70 94 84 67 62 64

2 68 71 54 83 64 18 22 83 91
99 58 44 62 69 60 54 60 46 38

10 30 20 20 40 25 24 58 71 74
75 50 35 30 8 38 42 69 71 78

87 18 13 82 62 58 45 41 44 4
76 40 40 7 32 35 21 26 35 50]

Let the number of operation points N = 40 and their coordinates are as follow. Adopt the encoding mode mentioned in the last section, set initial temperature 73150.8, cooling rate 0.01, threshold 500, Metropolis step size 3.5. Then, try it on computer. The result simulation is as follow:

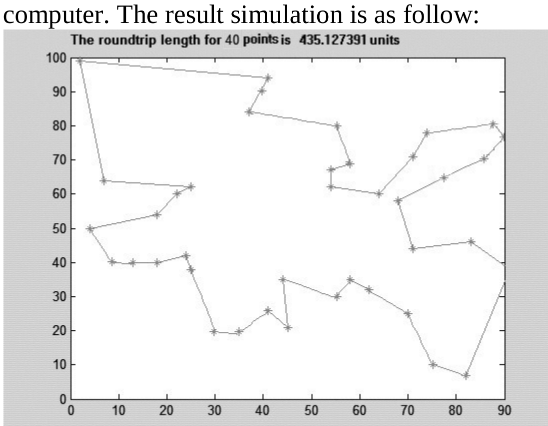

Figure 3: Simulation result of the case

Run it on computer for about 10 seconds and the result is shown in figure 3. the total length of shortest transport loop of construction materials is 435.127(optimum value d=428.901). The above experimental results show that the simulated annealing can quickly obtain the optimal solution of building materials logistics route under low-carbon economy [10].

From the above data, we can know simulated annealing can rapidly acquire the effective optimum solution of building energy-saving and is an effective algorithm for resources allocation of building energy-saving.

7. CONCLUSION

Simulated annealing algorithm is the search process by giving a time-change and ultimately tends to zero the probability of jumps, and thus can effectively avoid falling into local minima and ultimately tends to the global optimum of the serial structure of the optimization algorithm. It can quickly obtain the optimal solution of building materials logistics route under low-carbon economy, which is an effective algorithm for obtaining the building materials resources allocation scheme under low-carbon economy.

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