Transmission Path Planning based on Improved Artificial Potential Field and Enhanced Ant Colony Algorithm

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Keywords: Transmission Path Planning; Geographic Information Systems; Principal Component Analysis; BP Neural Network Algorithm; Artificial Potential Field; Ant Colony Algorithm

Abstract: Using geographic information system (GIS) as the information platform, Based on the cost standard of typical transmission lines of 500kv power transmission and transformation project of State Grid Corporation of China, the clustering of environmental influencing factors was analyzed by principal component analysis. On this basis, the comprehensive cost of unit grid is evaluated by BP neural network, and the final comprehensive cost matrix of unit grid is obtained. Based on the principle of minimizing the cost of grid construction, the proposed grid region transmission path is searched by ant colony algorithm. Considering the environmental constraints of the search area, the corresponding cost compensation mechanism and avoidance crossing mechanism are set for regions with different degrees of constraint capacity to improve the environmental resultant force. An improved artificial potential field is introduced to estimate the starting direction of the path of the ant colony algorithm. The optimal corner processing mechanism is added to further reduce the comprehensive cost of transmission lines and improve the convergence speed of the algorithm.

1. Introduction

The transmission line is the main structure of the grid, which undertakes the task of long-distance and large capacity power transmission. The main objectives of transmission line construction are to minimize the construction cost of the power grid and to minimize the transaction cost of the market [1].The planning decision is made by comprehensively considering the influence factors such as the terrain, geology, landform, wind speed, air quality, air temperature, human factors, transportation facilities and nature reserves in the planned area.

GIS [2] is widely used because of its scientific nature and timeliness. Literature [3] ranked the influence degree of the cost items in power grid planning through principal component analysis. In this paper, the typical cost of 500kv power transmission and transformation project of state grid corporation of China is taken as the reference [4], and BP neural network algorithm [5,6] is used to analyze the environmental impact factors and to evaluate the comprehensive cost of grid planning area in combination with principal component analysis.

Literature [7] studied the expansion of power grid based on ant colony algorithm. In this paper, according to the environmental limitation characteristics and cost optimization principle of transmission planning, the crossing and avoidance rules of different regions are set, the artificial potential field is introduced to screen the search direction, the ant colony pheromone is iteratively strengthened according to the optimal cost principle, and the transfer probability is optimized, so as to ensure the efficiency of the algorithm and the scientificity of the planning purpose.

2. Comprehensive Cost Assessment of Grid

In the transmission line construction, the comprehensive construction cost will change due to the influence of terrain and geomorphic factors such as hills, river network, mountains, ice cover, pollution and military facilities. The comprehensive cost assessment of the raster simulation area of the proposed construction path is the search basis of the improved ant colony algorithm under artificial potential field.

2.1. Unit Grid Determination

Unit grid size factor ξ is determined by the actual environment and real-time line construction standard, i.e., according to the expected distance between adjacent construction time transmission line tower as the foundation of grid size, combining with the different circumstances of adjacent tower distance ξ epsilon standards set up corresponding grid size. The distance between adjacent transmission towers in some years are shown as Table 1.

For unit grid size ξ and adjacent tower distance ε :

$$\xi = 1/\varepsilon \tag{1}$$

Table 1 Distance between adjacent transmission towers in some years.

Year	2006	2008	2010	2012
Number of towerss	2.26	2.19	2.15	2.15
Distance between adjacent towers	0.442	0.457	0.442	0.442

2.2. Principal Component Analysis of Factors Affecting the Comprehensive Cost Value of Grid

For the analysis of grid comprehensive cost, according to the literature, a total of 11 influencing factors, including air quality, wind speed, ice cover, pollution, air temperature, flat land, hills, mountains, river network swamp, geology and land use type, are taken as the main component analysis objects.

The eigenvalue $\lambda_1, \lambda_2, \cdots, \lambda_p$ of the correlation coefficient matrix R and the corresponding eigenvector $a_i = (a_{i1}, a_{i2}, \cdots, a_{ip})$ are calculated.

Establish the principal component

The subfactor influence vector of the observation matrix is denoted as:

$$X_i = \begin{bmatrix} x_{1i} \\ x_{2i} \\ \vdots \\ x_{Ni} \end{bmatrix}, i = 1, 2, \cdots, p \tag{2}$$

For principal component Z_i and principal component matrix Z,

$$\begin{cases} Z_i = a_{i1}X_1 + a_{i2}X_2 + \cdots + a_{ip}X_p \overset{\Delta}{=} a_i^T X \\ Z = a_1X_1 + a_2X_2 + \cdots a_pX_p \overset{\Delta}{=} a^T X \end{cases} \tag{3}$$

Among them, $a = (a_1, a_2, \cdots a_p)^T$, $a_i = (a_{i1}, a_{i2}, \cdots a_{ip})^T$, $X = (X_1, X_2, \cdots X_p)^T$, $\mathrm{i} = (1, 2, \cdots p)$

Contribution rate of principal component Z_i :

$$\varsigma_i = \frac{\lambda_i}{\sum_{k=1}^{p} \lambda_k} \tag{4}$$

For p=11 influencing factors, by comparing the size of elements in the eigenvector a_i along the order of influence of principal component Z_i, it can be obtained that p=11 influencing factors of comprehensive cost determine the ability and influence direction of comprehensive cost.

2.3. Comprehensive Cost Evaluation of Grid by BP Neural Network

BP neural network is used to study the comprehensive cost in different real environments to evaluate the comprehensive cost of simulated grid. The BP neural network is used to predict the comprehensive cost of transmission line under different environmental conditions.

The planned transmission line is 500kv transmission line in Liaoning Province, with the maximum wind speed of 27m/s and the maximum ice cover of 10mm. The specific reference is made to the transmission line cost under different terrain in the typical construction cost report of state grid corporation of China's power transmission and transformation project.

Considering that the influence of various factors on generation value is non-linear, from the perspective of objective experience, the three-layer BP neural network algorithm shown in Fig. 1 is adopted to complete the comprehensive cost assessment based on the actual construction situation. The intermediate layer neural network was obtained by inputting the samples from the data of transmission lines constructed in the same meteorological area. The simulated grid matrix obtained after the rasterization of the planned area was predicted by BP neural network, and the basic comprehensive cost matrix was obtained. The category II non-conventional crossing area grids located in military facilities, power transmission facilities, transportation facilities, ecological protection areas, etc., are given extra special crossing costs and compensation to form the final comprehensive cost matrix of all grids in the planning area. The costs that should not be routinely crossed are shown in Table 2.

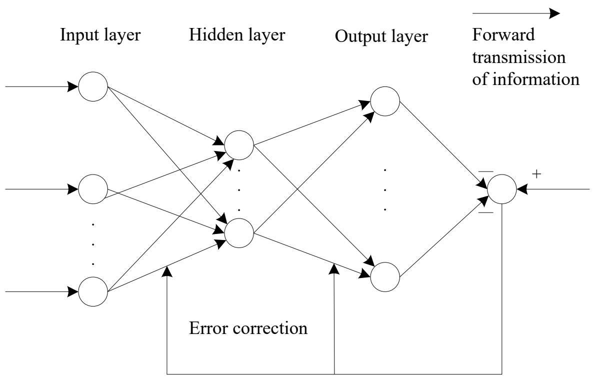

Figure 1 Schematic diagram of 3 layer BP neural network model.

Table 2 Costs that should not be routinely crossed.

Category II region type	The standard cost/(Ten thousand yuan $\cdot km^{-1}$)
Spanning 110kv transmission lines	10.2
Spanning 35kv transmission lines	6.5
Spanning 10kv transmission lines	3.1
Non-motorway	7.8
Motorway	10.9
Over the house	1.1
Ecologically protected area	$\sigma^* \cdot d_j$

2.4. Relative Comprehensive Cost Per Unit Grid

In order to facilitate subsequent improved artificial potential field and ant colony algorithm search, will be the final comprehensive cost matrix $\underline{\Delta}$ standardizing, and to ensure that the unit grid after processing the dimensionless relative comprehensive cost value σ_{ij} relative comprehensive cost v_{ij} is related with the original grid, approach is as follows:

$$\sigma_{ij} = \frac{v_{ij} - v_j^r}{v_j^q - v_j^r} \tag{5}$$

Where, σ_{ij} is the comprehensive cost of unit grid within the planning area, $v_j^q = \max\{v_j\}$, $v_j^r = \min\{v_j\}$.

3. Improved Transmission Path Planning Model of Ant Colony Algorithm

3.1. The Introduction of Ant Colony Algorithm

Ant colony algorithm is a bionic algorithm proposed by Italian scholar m. dorigo in the 1990s. Its basic principle comes from the study of ant foraging in nature. When the ant colony algorithm is introduced, the substation in the designated area and the planned transmission path are simplified into the road between the city and the neighboring city respectively, and the basis of the transmission path model is transformed into the classical TSP problem.

The traditional ant colony algorithm consists of four parts: pheromone rule, movement rule, propagation pheromone and avoidance rule. Each ant searches the foraging path according to these three principles, and the search method is shown in Fig. 2.

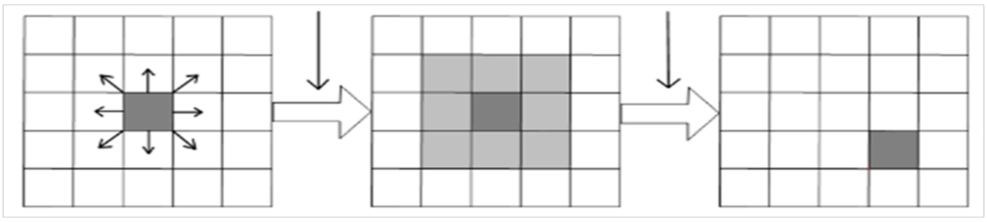

Figure 2 Schematic of ant colony searching.

3.2. Improved Ant Colony Algorithm for Transmission Lines

3.2.1. Information Recursive Reinforcement based on the Principle of Survival of the Fittest

Based on the principle of survival of the fittest in nature, the natural world will allocate resources to the superior among the groups with the same status through the competition among the groups, and then complete the survival of the fittest among the groups. In order to improve the convergence speed of the algorithm and avoid the local optimal dilemma, the recursive relation of information concentration is strengthened based on the principle of survival of the fittest:

$$\begin{cases} \tau_{oi}(t+1) = (1-p)\cdot\tau_{oi}(t) + \sum_{k=1}^{m}\Delta\tau_{oi}^{k} + \lambda\left(\Delta_{oi}^{q} - \Delta_{oi}^{r}\right) \\ \lambda = \dfrac{\Delta_{oi}^{q} - \Delta_{oi}^{hm}}{\Delta_{oi}^{hm} - \Delta_{oi}^{r}} \end{cases} \tag{6}$$

Where, λ is the strength parameter of survival of the fittest, Δ_{oi}^{hm} is the harmonic average value of increased pheromone concentration of all ants on the path of oi in the last cycle, Δ_{oi}^{q} and Δ_{oi}^{r} are the maximum and minimum values of increased pheromone concentration in the last cycle, and $p(0 < p < 1)$ represents the degree of pheromone volatilization.

3.2.2. Improved Transfer Probability

In ant colony algorithm, in the process of searching the path, ants will inevitably encounter the situation where all the surrounding feasibility grids are of high comprehensive cost, resulting in ant k staying in the same place.

By modifying the heuristic function η^k, the transfer probability p^k of ant k is improved. This strategy is adopted to increase the flow factor and improve the efficiency of the algorithm.

$$\eta_{oi}^{'k} = \begin{cases} 1 - \dfrac{\sigma_{oi}\cdot d_{oi} + s_{oi}^{l}}{\sum_{s\in allow_k}^{m}\sigma_{oi}\cdot d_{oi} + s_{oi}^{l}} & , s \in allow_k \\ 0 & , s \notin allow_k \end{cases} \tag{7}$$

Where, σ_{oi} is the relative comprehensive cost of the transmission line on path oi (as mentioned above), and d_{oi} is the distance of path oi; s_{oi}^{l} is the shortest distance between oi calculated by Dijkstra algorithm.

3.2.3. The Initial Direction of Repulsion Calculation of Artificial Potential Field is Improved

The artificial potential field algorithm is a virtual force method first proposed by Khatib and Krogh. The basic idea is to add a virtual artificial force field in the moving environment of ants, so that obstacles and target points generate repulsion and attraction to ants respectively. The principle of introducing artificial potential field into transmission path planning is to simulate the relatively high cost construction environment in GIS cost matrix as an obstacle and the transmission target as a target point, so as to optimize the search ability of the algorithm and improve the convergence speed of the algorithm.

In the geographic grid map, the center grid is set as the starting point, and the ant can only advance to the eight adjacent grids

For the initial grid X (i,j), assuming that the comprehensive cost of the 8 grids around it is continuously changing.

The relative comprehensive cost value and the repulsion force on the 9 grids in the 3×3 grid area centered on the initial grid are constructed, respectively, the comprehensive direction cost matrix ε_{ij} and the optimal cost direction matrix $F_{ij}^{'}$, and the force direction matrix $F_{ij} = \varepsilon_{ij} * F_{ij}^{'}$ is defined.

Among them:

$$\varepsilon_{ij} = \begin{bmatrix} \sigma(i-1, j+1) & \sigma(i, j+1) & \sigma(i+1, j+1) \\ \sigma(i-1, j) & \sigma(i, j) & \sigma(i+1, j) \\ \sigma(i-1, j-1) & \sigma(i, j-1) & \sigma(i+1, j-1) \end{bmatrix} \tag{8}$$

$$F_{ij}^{'} = \begin{bmatrix} f(i-1, j+1) & f(i, j+1) & f(i+1, j+1) \\ f(i-1, j) & f(i, j) & f(i+1, j) \\ f(i-1, j-1) & f(i, j-1) & f(i+1, j-1) \end{bmatrix} \tag{9}$$

* is the convolution of two matrices; for the comprehensive direction cost matrix ε_{ij}, $\sigma(x, y)$ is the relative comprehensive path cost to the corresponding grid; For the optimal cost direction matrix $F_{ij}^{'}$, $f(x, y)$ is the projection value of the repulsion vector F_C along the corresponding raster direction, and $\vec{\delta}(x, y)$ is the direction vector in the corresponding direction. Should satisfy:

$$\begin{cases} F_C = \sum\limits_{\substack{i-1 \le x \le i+1; \\ j-1 \le y \le j+1}} f(x, y) \cdot \vec{\delta}(x, y) \\ f(x, y) \ge 0 \cup f(i, j) = 0 \end{cases} \tag{10}$$

Under the action of the same target gravity, the ants will search along the direction interval with the highest net force, that is, $\bar{F}_{ij} = \min\{F_{ij}\}$.

3.2.4. Line Corner Optimal Comparison Mechanism

Taking the construction of 500kv transmission line as an example, according to the literature, the tower construction cost accounts for about 30%-40% of the construction cost of the transmission line. The cost proportion under different terrains is shown in Fig. 3.When searching the path, the ant colony may have more turns in the search path due to the influence of the improved artificial potential field algorithm on the starting direction, which will greatly increase the number of corner tower construction and cause a meaningless cost increase. In order to avoid this kind of situation, the comprehensive cost value of corner tower is compared to make a choice between two local paths.

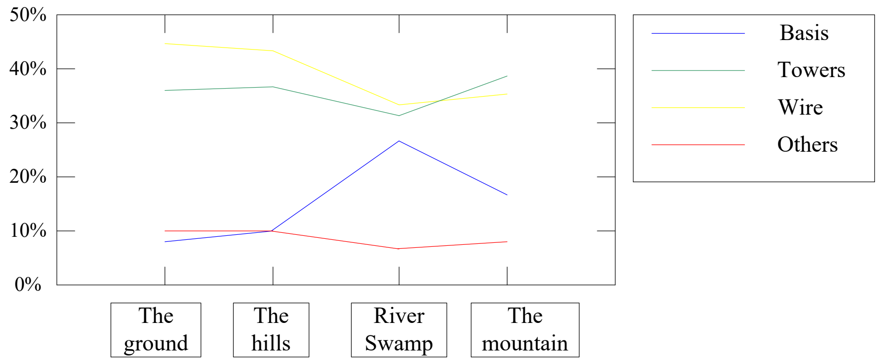

Figure 3 Construction cost ratio of transmission lines under different terrains.

The two local paths are shown in figure 5. Path a (as shown on the left) reaches point E through AB, BC, CD, and DE. Path b does not cross the category III region (as shown in the right figure), and it can go directly from point A to point D.

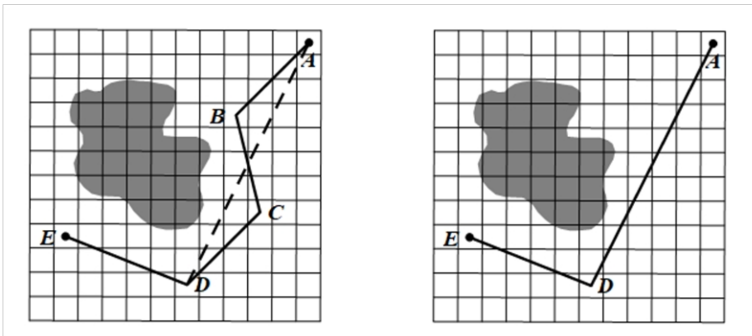

Figure 4 Two path selection schemes under the corner processing mechanism.

On the premise that the two path construction methods are in line with the actual requirements, let path a (as shown in Fig. a) be the construction plan for setting the corner tower, and path b (as shown in Fig. b) be the construction plan for reducing the construction of the corner tower, and ϑ_a and be the corresponding local path comprehensive cost. For the relative comprehensive costs and ϑ_b that pass through the grid on the two paths, the optimal cost selection model is obtained as follows:

$$\text{choice}\{a,b\} = \min\{\vartheta_a, \vartheta_b\} = \min\left\{\int \sigma_a dl, \int \sigma_b dl + \sum_{i=1}^{h} T_i\right\} \tag{11}$$

Where, h is the number of additional corner tower set in path a, and T_i is the construction cost of corresponding tower.

As shown in Fig. 5, for class III non-traversal grid area, construction plan a with multiple corner towers can only be used to ensure the system stability of the simulated grid area.

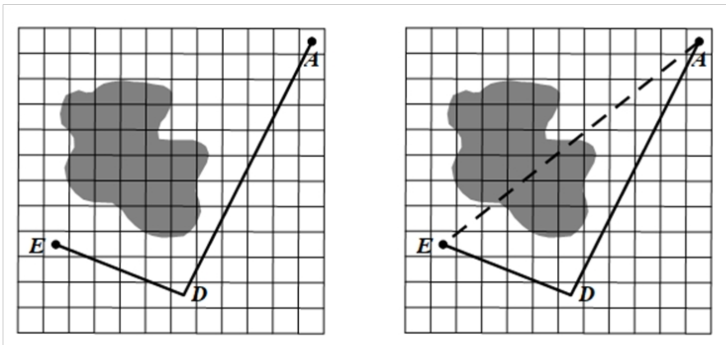

Figure 5 Two kinds of path choices in the third type of non-cr ossable area.

4. Transmission Path Comprehensive Search Algorithm Flow

Through principal component analysis and BP neural network, factors affecting the comprehensive cost of unit grid were analyzed and value was predicted. Based on the improved artificial potential field and the enhanced ant colony algorithm, the transmission lines in the target area are planned. At the same time, in order to ensure that the search path will not have a cycle, the searched area and the non-crossable area (such as the airport) are defined as the category III area, that is, the ant's proposed search area can only be located in the category I region that the ant does not pass through or in the category II region that the ant does not pass through. When the search is completed, the collection of routes formed in the region of class I and class II is the final planning path of the transmission line.

5. Experimental Simulation Analysis

According to the above model, combined with MATLAB and ArcGis engine 10.0 as the algorithm development platform, a 500kv transmission path planning region in LiaoNing province is taken as an example. The region is 22.36km long from north to south and 26.58 km wide from east to west. The following figure is the GIS remote sensing information map of the region and the MATLAB Lowess 3D cost map evaluated by BP neural network algorithm. The enhanced ant colony algorithm with improved artificial potential field is used to search the transmission path in the planned area.

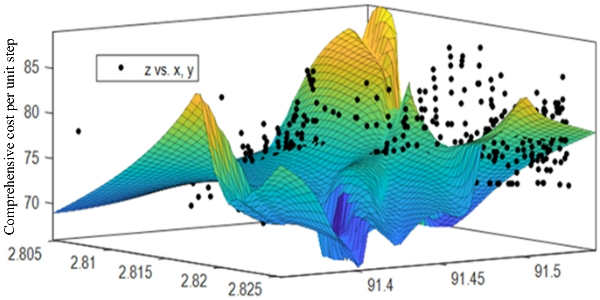

Figure 6 Three-dimen sional comprehensive .

cost map of the planned regional unit grid

Figure 7 Planned regional remotesensing information map based on GIS.

5.1. GIS Geographic Information Rasterization

Considering the average distance between adjacent towers in the transmission line construction in the planned area, the unit grid length is set as 0.25km. In line with the size of the algorithm data, it also fits the actual line construction step size. The ArcGis tool is used to transform the map of the planned area into the original raster information matrix. Meanwhile, the elevation data of the original GIS information matrix is converted into slope data. According to the environmental conditions, the region is divided into: category I conventionally traversable region, category II conventionally untraversable region, category III searched region and environmentally untraversable region. The first two types of regional comprehensive costs were evaluated according to BP neural network, and the category II region was compensated according to Table 2. For category III region, the grid comprehensive cost was set to -999 to obtain the final grid comprehensive cost matrix.

5.2. Principal Component Analysis of the Factors Affecting the Comprehensive Cost of Grid

Principal component analysis was carried out on 11 influencing factors, including air quality, wind speed, ice cover, pollution, air temperature, flatland, hills, mountains, river network marshes, geology and land use type. The principal component was used to divide the 11 influencing factors into three clusters: climate, topographic geology and geomorphology. The corresponding relation and results are shown in Table 3.

Table 3 Principal component analysis results of impact clustering.

Influence clustering	Topography and geology	Attachment	Climate
Z_1	0.3919	0.3845	0.1182
Z_2	-0.0210	0.0221	0.2778
Subinfluencing factor	Terrain, geology, land use type	Ice and dirt	The wind temperature, wind speed, temperature

Among them, terrain clustering includes four influencing factors: flat land, hilly land, mountain land and river network swamp.

5.3. Among Them, Terrain Clustering Includes Four Influencing Factors: Flat Land, Hilly Land, Mountain Land and River Network Swamp.

Set the search step length to 250m; Edge pheromone evaporation coefficient $p = 0.4$, pheromone persistence coefficient $1 - p = 0.6$, pheromone important factor $p = 1.2$, visibility control factor $p = 0.8$; Ant colony size 100 groups, each group of 50.

5.4. Analysis of Simulation Results

In order to verify the convergence speed and operation effect of the algorithm, the improved ant colony algorithm and the traditional ant colony algorithm and Dijkstra algorithm mentioned in literature were tested respectively. The search results of Dijkstra algorithm have not been obtained after the time limit is exceeded. The results of the three algorithms are compared as follows Table 4:

Table 4 Comparison of enhanced ant colony algorithm and traditional algorithm.

The algorithm name	The running time/s	The number of inflection point	The Alternate number	Average cost per unit step
Enhanced ant colony algorithm	74	5	0	77.83
Traditional ant colony algorithm	107	17	2	83.65
Dijkstra algorithm	--	--	--	--

The unit step cost refers to the average construction cost of each step long distance transmission line.

As shown in Fig. 8, the search paths of the enhanced ant colony algorithm (Fig. Right) and the traditional ant colony algorithm (Fig. Left) are compared:

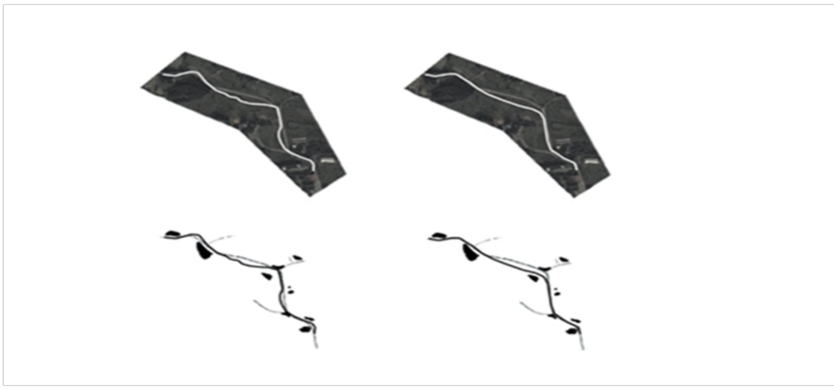

Figure 8 Comparison of searching paths between two ant colony algorithms.

Through comparison, it can be found that adding artificial potential field at the initial stage can improve the directivity of the algorithm to the search direction and improve the convergence rate of the transfer probability of ant colony algorithm. Through the classification of regional feasibility, the accuracy is improved, the number of inflection points is greatly reduced, and the occurrence of circuitous points is avoided.

On the comprehensive cost with the step length of 250m, the cost of the traditional algorithm is reduced to a certain extent through the evaluation of BP neural network, and the algorithm is more efficient and less expensive, so the improvement and reinforcement are reasonable and effective.

6. Conclusion

In this paper, Arc Gis is used as the geographic information collection and analysis platform, and the influence factor matrix of the planned area is analyzed by cluster principal component analysis, so as to obtain the order of influence degree; On this basis, the unit grid comprehensive cost matrix is obtained by evaluating the unit grid comprehensive cost through the three-layer BP neural network.

Based on ant colony algorithm, the convergence rate of the algorithm is improved by strengthening the iteration relation of pheromone concentration and the definition of transfer probability. The transmission path cost is reduced by introducing the optimal corner processing mechanism. On the basis of ant colony algorithm, an improved artificial potential field was introduced to predict the starting direction of ant to reduce the running time of the algorithm.

Taking the typical cost of power transmission and transformation project of the State Grid Corporation of China as the reference standard, the grid treatment method is adopted to improve the actual fitting of the algorithm by setting the crossing mechanism and the avoidance mechanism for the environment in the proposed construction area.

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