Low-carbon optimization of spatial pattern in Shenfu New District based on genetic algorithm

Peiwen Jia[1], Shilei Fu[1,2], Zhenxing Li[1] and Huan He[1]

[1]College of Architecture and Planning, Shenyang Architecture University, Shenyang, Liaoning Province, China

[2]E-mail: fsl116@foxmail.com

Abstract. The realization of low-carbon development is the key to solving the global climate change problem. China's total carbon emissions share in the world is increasing year by year. Taking the road of low-carbon city development is the inevitable trend of China's city development in the future. Increasing the concentration of urban land space can improve energy utilization and achieve the optimal goal of energy conservation and emission reduction. Genetic algorithm is a method to search the optimal solution by simulating the natural evolution process, providing a scientific solution for low-carbon city planning. This paper starts with the spatial arrangement of land use, minimizes people's spatial travel distance through the global optimization ability of genetic algorithm. It summarizes the low-carbon spatial organization characteristics of Shenyang-Fushun New City, explores the analysis method of urban spatial low-carbon pattern, puts forward the optimization strategies of urban spatial structure, urban transportation network, green space system and low-carbon industrial layout, adjusts the development trend of urban areas, promotes low-carbon living and production behaviours, and provides theoretical basis and practical experience for the planning of low-carbon cities.

1. Introduction

1.1. Research background

China's development of low-carbon eco-city is an inevitable choice to promote new urbanization. The Party's "19th Congress" proposed that China should promote green development, establish and perfect a green and low-carbon circular economic system, and advocate a simple and moderate, green and low-carbon lifestyle [1]. Traditional planning methods mostly use qualitative methods to analyze and plan or the models built are mostly single-level optimization problems, which make it difficult to find the most ideal low-carbon solution. Genetic algorithm is a method to search for the optimal solution by simulating the natural evolution process. It, with better global optimization ability, can automatically obtain and guide the optimized search space, adaptively adjust the search direction, and can provide scientific solutions for low-carbon city planning [2].

The optimization of urban low-carbon spatial pattern includes both quantity distribution and spatial distribution. In the pattern optimization, the key to realize a low-carbon city is to study the effect of the spatial pattern of land use on reducing urban carbon emissions and environmental pressure, and how to combine with economic benefits and other factors to jointly establish a multi-objective optimal allocation model of land use under certain constraints .Under the guidance of low carbon as the goal, this paper introduces genetic optimization algorithm to coordinate multiple goals between urban land use form and low carbon orientation, in order to form an ideal low carbon urban space form.

1.2. Overview of research area

Shenyang-Fushun connection zone is located in the eastern part of Shenyang city and the western part of Fushun city in Liao Ning province, with an area of 605.34 square kilometers. Shenyang-Fushun New District is located in the middle of Shenyang-Fushun connection zone, with obvious advantages in location conditions (Fig. 1). Shenfu New District is adjacent to Shenyang's ecological conservation zone in the west and Fushun's key development zone in the east. Fushun City has built a large number of industrial parks in the new town. There are industries with high pollution and energy consumption, which conflict with Shenyang's development orientation. Ecological protection and economic development are the difficult problems facing the new district. It is urgent to promote the green and low-carbon development of Shenfu New Town and optimize the spatial structure of the new town in an all-round way.
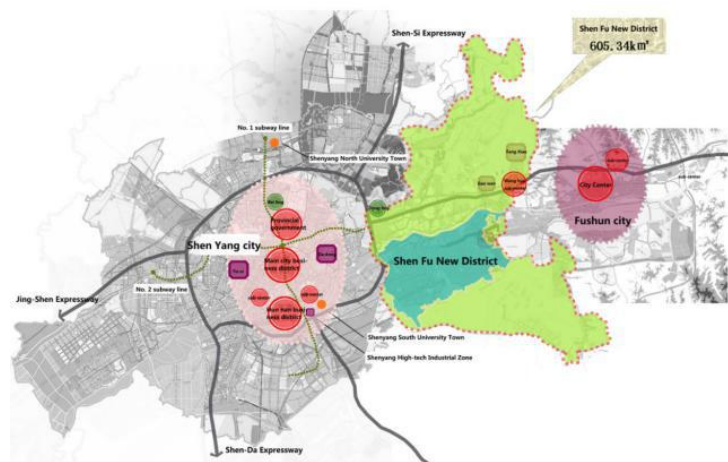

Figure 1. Map of Shenfu New District.

2. Application of Genetic Algorithm in Spatial Optimization of Shenfu New District

2.1. Model Optimization Ideas and Data Acquisition

2.1.1. Optimization Ideas. According to the low-carbon planning objectives, land use status and socio-economic basis of Shenfu New District, a low-carbon spatial optimization model is constructed, the constraints in the model are defined, and decision variables are selected according to the objective function to understand the phenotype of each individual and the scope of solution. According to the low-carbon space optimization model, the target system and the constraint system are determined to determine the fitness value, and the decision-making genetic algorithm is used to optimize the allocation operation to form the low-carbon space optimization model of Shenfu New District [3] (Fig. 2).
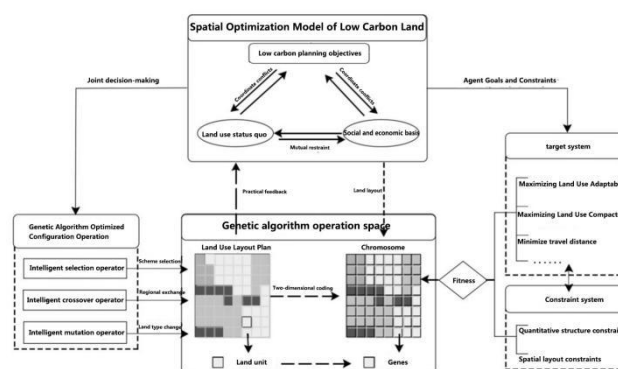
Figure 2. Genetic Algorithm Model Frame Diagram.

2.1.2. Data Acquisition. Based on the remote sensing images of Shenfu New District, the geographic spatial information units in the remote sensing images are identified and rasterized. Each grid is taken as the basic unit in the study, and the study area is divided into 5177 grids with the same specifications by using a grid of 200m×200m, and this is taken as the basic data for empirical analysis. In the optimization process, these small squares are used as optimization units to establish layers and various land numbers. According to the output of current land types, the research obtains the database of current unit land use (Fig. 3) [4].
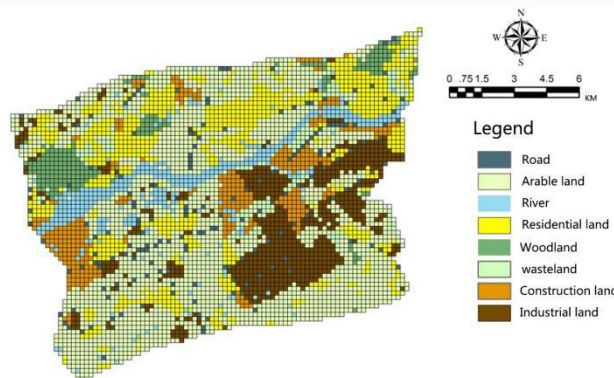
Figure 3. The current land grid map of the study area.

2.2. Construction of Low Carbon Space Optimization Model

2.2.1. Model selection. In this paper, the multi-objective optimization model is selected. The development of many factors in land use is not only restricted by the subjective factors of decision makers, but also influenced by various objective factors, which makes the land use structure more scientific and reasonable. All variables should be comprehensively analyzed, and the subjective and objective factors that may affect the overall objective should be analyzed one by one, so as to improve the overall optimization. The optimization mathematical model can be expressed by formula (1) [5]:

$$\begin{cases} opt\ \mathrm{Z} = \alpha f(x_1) * \beta f(x_2) * \gamma f(x_3) * \delta f(x_4) \\ \qquad s.t\ \ g(x) \geq B \\ \qquad\qquad x \geq 0 \end{cases} \tag{1}$$

In the formula: Opt-Fitness z value; f(x) -objective function; β -Weight of objective function 2; γ-Weight of objective function 3; g(x)-Constraint function; x-decision variable.

2.2.2. Construction of Objective Function. The objective of this paper is to construct the objective function of low-carbon land use structure optimization in Shenfu New District by integrating low carbon, ecology and current situation. For the sake of simplification, we actually set 5 types of land in the model, of which road land is a linear element and cannot be reflected in grid blocks, so it is divided equally into other land units. Leisure land includes green land and square land and land for public management and public service facilities. The working land includes three types of land: industrial land, storage and logistics land and public facilities land. The corresponding relations between codes and land types are: 1 - residential land, 2 - commercial land, 3 - working land, 4 - leisure land, 5 - unused land, and 0-non-calculation object.

In this paper, the targets shown in equations (2) to (5) are selected as optimization targets.

The objective of maximizing land use suitability is to make the spatial arrangement of land more suitable for the current geological, topographic, hydrological and other natural conditions through the extraction of land use suitability, to find out the suitable arrangement areas for each type of land, and to standardize the rationality of optimal arrangement.

$$maxZ = \Sigma f_{(x1)} + \Sigma f_{(x2)} + \Sigma f_{(x3)} + \Sigma f_{(x4)} \tag{2}$$

In the formula: $maxZ$ is the land use suitability value; $f_{(x)}$ is the land suitability value corresponding to the decision variables.

Maximizing land use compactness target is to increase the spatial concentration of industries, realize labor market sharing, improve energy utilization rate, and achieve the optimal goal of energy conservation and emission reduction. This paper sets the goal of maximum land compactness to reflect the utility of land spatial agglomeration in low-carbon cities.

$$\max \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{k=1}^{K} \frac{\sum_{i',j' \in Nei} X_{i'j'k} \exp(-dist_{ij,i'j'}/\lambda)}{\sum_{dist_{ij,i'j'}} \exp(-dist_{ij,i'j'}/\lambda)} X_{ijk} \tag{3}$$

Nei represents the neighborhood of the cell (i, j); Dist i j, i'j' represents Manhattan distance of two units (i, j) and (i', j') of land use type k; λ is the adjustment coefficient.

Maximizing the land mix target is that the land mix can be reflected by travel distance, which reflects the low-carbon degree of the city, as well as by the distance between housing and the nearest work place, shopping center and leisure center. Exponential distance attenuation function is adopted in the model to express its spatial attraction to position.

$$E_{distance} = c_1 A_1 e^{-B_1 D_{work}} + c_2 A_2 e^{-B_2 D_{shop}} + c_3 A_3 e^{-B_3 D_{leisure}} \tag{4}$$

$E_{distance}$ is low-carbon trip distance evaluation. $c1$, $c2$ and $c3$ are the weight coefficients of each distance influence factor, $c1+c2+c3 = 1$, $C1 > C2 > C3$. $A1$, $A2$ and $A3$ are the intensity coefficients of spatial influence. $B1$, $B2$ and $B3$ are the attenuation coefficients of spatial influence, and Dwork is the distance to the work center. Dshop is the distance to the shopping center. Middleware is the distance to the Dleisure center.

Minimize the goal of land conversion cost: spatial optimization of urban land will result in a change in the current use of some units of urban land. The goal of establishing the cost function of urban land type conversion is to minimize the conversion cost as much as possible.

$$\min \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{k=1}^{K} c_{ijk} x_{ijk} \tag{5}$$

C_{ijk} indicates the cost of arranging K types of land use at the locations of units (i,j); X_{ijk} is a variable. If the land use type of units (i,j), (i',j') is K, its value is 1, otherwise it is 0; K represents the land use type of unit (i,j).

2.2.3. Construction of Constraints. In this paper, economic benefits and ecological benefits are placed in the system of constructing objective function, and low-carbon benefits are taken as the main constraint conditions. Respectively from the land quantity, the population quantity, the present situation condition and unifies the Shenfu New District land plan and the actual situation and so on 11 aspects carries on the restraint to the Shenfu New District land.

The number of each type of land use must meet a predefined structural ratio.

$$\sum_{i=1}^{N} \sum_{j=1}^{M} X_{ijk} = X_k, \forall k \tag{6}$$

Every space unit must have a land use.

$$\sum_{k=1}^{K} X_{ijk} = 1, \forall ij \tag{7}$$

One land unit is at least adjacent to another.

$$S_{L_{ij,i'j'}} \geq 1, \forall (ij, i'j') \tag{8}$$

Spatial adjacency constraints of the same type of land use units. It is better to form a complete plot of land for units with the same land use. This is a planning need, so that each type of land will not be

fragmented in spatial distribution and will not cut off the close interrelation within a certain type of land. If the distance of 2 units (i1j1) and (i2j2) of land use type K is expressed.

$$m_{i_1 j_1 k, \ i_2 j_2 k} = 1 \qquad (9)$$

Distance constraint. It is necessary to keep a certain distance between certain land use types. If the Euclidean distance between the unit ($i_1 \ j_1$) with land use type k1 and the unit ($I_2 J_2$) with land use type k2 is required to be greater than D, the distance constraint can be expressed as follows:

$$d_{i_1 j_1 k, \ i_2 j_2 k} > D \qquad (10)$$

Direction constraint. For example, factories with serious air pollution should choose the downwind direction in densely populated cities. If B_{ij} represents a set of units in a plot unit (ij) forbidden area:

$$i \notin B_{ij} \quad and \quad j \notin B_{ij} \qquad (11)$$

The total area of the land is about 10,000 square meters. TL is the total land area of 42.55 (hm^2).

$$\Sigma_{i=1}^{8} x_i = TL \qquad (12)$$

Minimum area constraint of residential land: $1 \geq TBF$, where TBF is the land area 14 (hm^2) calculated according to the per capita residential area.

Minimum area constraint of management service facility land: $2 \geq TLt$, where TLt is 2.75 (hm^2) calculated according to the area of service facility per capita.

Constraint on green square area: $4 \leq UJL$, where UJL is the land area of 5(hm^2) calculated according to the per capita green square area.

Land conversion constraints: set constraints in basic farmland protection areas, rivers and lakes ecological protection areas and other areas to prohibit inappropriate land use conversion. Ω indicates a space control area; P(Xij) represents the conversion probability of plots (i, j).

$$P\big(X_{ij}\big) = 0, \ if(i, \ j \epsilon \Omega) \qquad (13)$$

2.3. Operation Flow of Genetic Algorithm

In the case of selecting the initial population, the target solution is gradually obtained by continuously selecting, crossing and mutating individuals in the population on the premise of a certain optimization target [6] (Fig. 4).
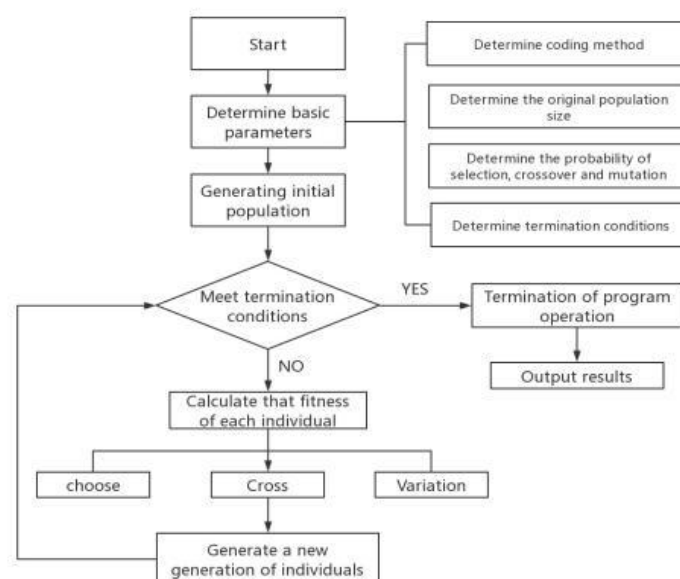

Figure 4. Genetic algorithm flow chart.

2.3.1. Initial Population Setting. The optimal layout of land space is mostly based on the current utilization, and there are many hard restrictions. For example, the current land use for water areas and water conservancy facilities will not be easily changed in general. Therefore, this paper must satisfy certain prior knowledge when generating the initial group. It is used in the optimization configuration, and it will not be considered in the unit optimization process where the purpose is clear and changes are not allowed, so they will not be coded, thus reducing the scale of the problem and improving the efficiency of the algorithm.

2.3.2. Determination of model fitness function. When constructing the fitness function, a dynamic penalty function method is introduced (i.e. the penalty factor changes continuously in the process of convergence). Its essence is:

For equality constraint $c_\tau(x) = 0$, constructor

$$\varphi(c_\tau(x)) = \begin{cases} 0, & \text{if } -\varepsilon \le c_\tau(x) \le \varepsilon \\ & \tau = 1, 2, \ldots, s \\ |c_\tau(x)|, & \text{else} \end{cases} \tag{14}$$

For inequality constraint $h_\omega(x) \le 0$, construct function

$$\Psi(h_\omega(x)) = \begin{cases} 0, & \text{if } h_\omega(x) \le -\varepsilon \\ & \omega = s+1, s+2, \ldots, M \\ |h_\omega(x)|, & \text{else} \end{cases} \tag{15}$$

Where: S is the number of equations in the constraint condition; M is the number of constraints; ε is Archimedes infinitesimal, that is, a number less than any positive number and greater than zero. Then the fitness function of genetic algorithm for minimizing constrained optimization problem is

$$\max f(x, \sigma_\theta) = -f_0(x) - \sigma_\theta \left[\sum_{\tau=1}^{s} \varphi^2(c_\tau(x)) + \sum_{\omega=s+1}^{M} \Psi^2(h_\omega(x)) \right] \tag{16}$$

Where: $f_0(x)$ is the original objective function; for the penalty factor, $=1/ = C$, $c \in (0,1)$, as evolution progresses, the penalty factor gradually increases, making the solution group more feasible.

2.3.3. Output of Optimization Results. The GA optimization module has an initial population size of 100, an optimized individual of 10, a population size of 600,000, a crossover probability of 0.75, a mutation probability of 0.1, and an evolution algebra of 1,000 generations. In this paper, Visual Studio software is selected as the platform to write the spatial configuration module of genetic algorithm. During the process of program operation, the evolution of the program gradually slows down and tends to be stable as time progresses. In the optimization module, the data obtained from the final results of optimization are re-imported into Arc Map for spatial display.
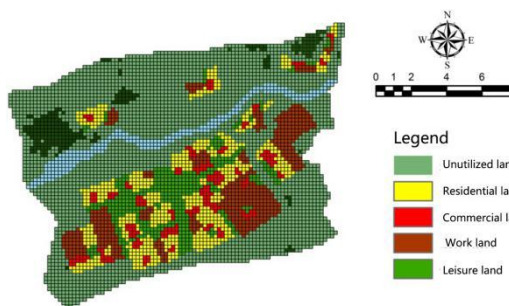

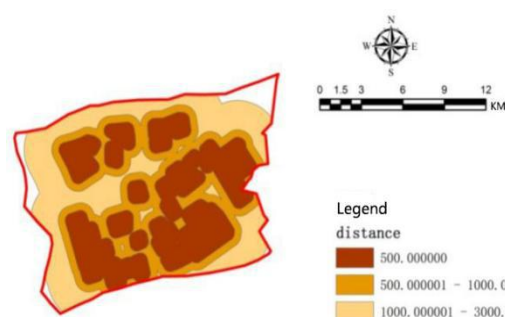**Figure 5.** Simulation optimization scheme.

Figure 6. Scope of work site services.

The simulation optimization in this paper has output a number of results, and the most representative scheme among them has been selected for in-depth study (Fig. 5). The optimization

results show that within the working travel radius of 500 meters, the construction land basically covers most areas, the 1000-meter range circle covers all areas except some leisure land, and the 3000-meter working travel range circle covers all planned land as shown in Fig. 6. The 500-meter travel radius of commercial land covers most of the built-up area, and the 1,000-meter range circle realizes the full coverage of residential land, for example, the 3,000-meter range circle realizes the full coverage of construction land, for example (Fig. 7); the 500-meter travel radius of leisure land covers most of the built-up area, and the 1,000-meter range covers all the construction land as shown in (Fig. 8). Therefore, the optimization results of the plan are in line with the low-carbon plan results expected in the previous period.
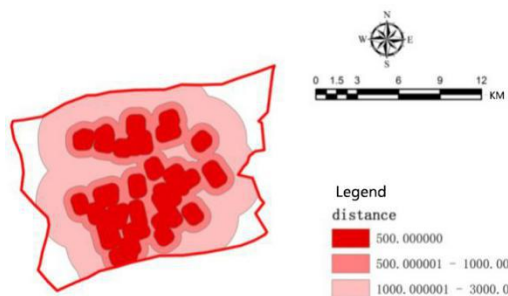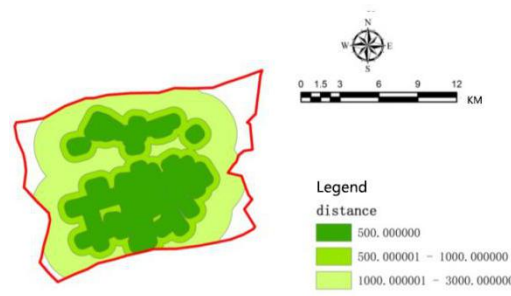

Figure 7. Scope of commercial land services.

Figure 8. Scope of leisure land services.

3. Low carbon spatial pattern optimization strategy

Based on the low-carbon land use zoning method, the optimized low-carbon land use structure in Shenfu New District is spatially distributed to achieve the goal of rational allocation of land resources and full realization of low-carbon utilization. The spatial layout is optimized and analyzed from four aspects: low-carbon land use spatial structure, low-carbon transportation system, low-carbon green space system and low-carbon industrial system [7].

3.1. Low-carbon Optimization of Urban Land Use Structure

In the planning scheme, centralized industrial layout is adopted, and the original industrial construction land is fully reserved in the optimization, thus reducing the planned land area of the urban built-up area and adjusting the planned population capacity (Fig. 9).In this plan, some residential land and commercial land in the north of Hunhe River will be adjusted to forest land or other land. There is a large area of wetland landscape in the south of Hunhe River, which has been preserved and renovated in the planning, forming a large area of ecological wetland. The industrial land of the whole land has retained the centralized layout mode, but the industries of different natures have been distributed to balance the travel distance of residents.The commercial area has been distributed in a scattered way [8], and the green space has been arranged to form a network layout mode. Broaden the ecological corridors on both sides of Hunhe River, together with the two ecological corridors in the north-south direction, thus strengthening the links between the north and south sides of Hunhe River.

Figure 9. Adjustment of Low Carbon Planning Plan.

3.2. Low-carbon Optimization of Urban Transportation System

Based on people's need for green travel, the plan is guided by the "B+R" system. By arranging bicycle parking facilities at bus stops and setting up a comfortable and convenient greenway network, people are encouraged to connect buses by riding or walking to reach their final destination and improve the coverage of the bus network [9]. In this paper, aiming at the green commuting preference and exercise travel needs of specific citizens, slow-moving networks such as riverside greenways, urban greenways and country greenways are planned and set up to meet the personalized travel needs of citizens(Fig. 10).

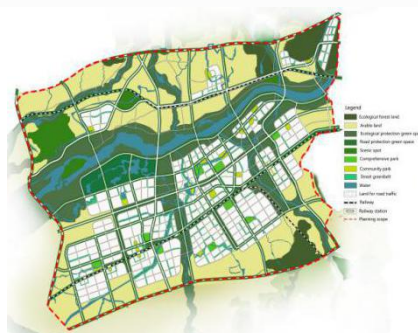| **Figure 10.** Low carbon greenway planning. | **Figure 11.** Green space system plan. | **Figure 12.** Industrial zoning layout. |

3.3. Low-carbon Optimization of Urban Green Space System

This paper adopts a spatial layout mode composed of three low-carbon layout modes of "oxygen source green space", "near source green space" and "carbon source green space" to form a low-carbon urban layout. The spatial layout mode of "large dispersion and small aggregation" will produce a spatial dispersion arrangement of carbon sources with large carbon emission, with a large area of oxygen source green space distributed on the periphery, forming a large-scale natural carbon sink absorption barrier around the city to prevent carbon dioxide from continuing to diffuse outward.

However, the local space adopts the layout mode of combining three levels of carbon source space, with near-source carbon sink greenbelts arranged between carbon sources to absorb carbon emissions from the local space nearby, which is also in line with the development direction of local "compact" cities [10] (Fig. 11).

3.4. Low-carbon Optimization of Urban Industrial System

Based on the industrial development structure of the connecting belt in Shenfu New District, this paper designs the spatial layout of the low-carbon industry in the plan. The industries in the plan are centrally arranged in the south of Hunhe River and distributed in the north of Hunhe River. The north

area is mainly divided into three regions, and the development of eco-agriculture, forestry and tourism experience industry is considered; the area south of Hunhe River is mainly divided into seven areas.

In order to reduce the impact on living, low-carbon scientific research industry and low-carbon service industry are arranged close to the urban area. The eastern area is updated and transformed into a high-tech industrial park. The southern area is transformed from the original status quo into a low-carbon equipment processing and manufacturing industrial park. A low-carbon automobile logistics industrial park is added to the western area.The adjustment of the whole industry has basically satisfied the residents' travel proximity and reached the low-carbon arrangement to guide residents' travel [11] (Fig. 12).

4. Conclusion

Low-carbon city is the inevitable choice to promote new urbanization. The spatial structure of land use and the rational layout of space are the foundation to realize the construction of low-carbon city in Shenfu New District. In this paper, genetic algorithm combined with spatial information technology is introduced to build a spatial layout model of urban land based on spatial travel distance, which guides urban residents to choose low-carbon travel modes spontaneously, and conducts low-carbon target-oriented simulation optimization on land use in Shenfu New District. In this paper, a multi-objective optimization model based on genetic algorithm is established to optimize and analyze the spatial layout of land use in Shenfu New District. The low-carbon spatial layout results obtained are used to guide the adjustment of the overall planning of Shenfu New Distric.

References

[1]   Meirong S U 2012 Hot thoughts on China's low-carbon cities: current situation, problems and trends *China population resources and environment* **3** p 48-56

[2]   Zhuo Yu and Zhihua Wu 2008 Research on urban spatial growth model based on Genetic *City planning* **5** p 83-88

[3]   Fei Chen, Dajian Zhu 2009 Connotation, Model and Target Strategy Determination of Low-carbon City Research *Journal of Urban Planning* **4** p 7-13

[4]   LIAO G C 2012 Intergrated isolation niche immune genetic algorithm for solving bid-based dynamic economic dispatch *International Journal of Electrical Power & Engery System* **42** p 264-275

[5]   Lili Zhang, Feng Zhang 2009 Complex constraint multi-objective optimization genetic algorithm based on population classification *Software guide* **12** p 38-42

[6]   Yang Zhou,Chang Gong and Pingping Xu 2017 Cloud computing workflow scheduling method based on dynamic target Genetic Algorithm *Natural science journal of Xiangtan University* **39** p 123-6

[7]   Haixiao Pan, Yi Tang and Jingyu Wu 2008 China's "Low Carbon City" Spatial Planning Strategy *Journal of Urban Planning* **6** p 57-64

[8]   Jiansheng Wu, Na Xu and Xiwen Zhang 2016 Evaluation and spatial pattern analysis of low-carbon cities in China *Progress in Geographical Science* **35** p 204-13

[9]   Jianqiang Hu, Jiaxiong Xu, Xianglin Jiang and Yaoting Zhu 2017 Research on Evaluation of Green Transportation Development Based on PSR Model *Traffic Energy Saving and Environmental Protection* **13** p 1-5

[10] Fangzheng Li, Xiong Li 2014 Research on Development Strategy of Low-carbon City Based on Greenway Network Construction *Journal of Theoretical Studies* **9** p 108-11

[11] Jian Li, Zhenzhen Hao 2014 Research on Low-carbon City Construction Based on Industrial Impact and Spatial Reconstruction *China population resources and environment* **24** p 65-72