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STUDY ON OPTIMIZATION OF COAL LOGISTICS NETWORK BASED ON HYBRID GENETIC ALGORITHM

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Abstract. *Coal is the main energy source in the world. The distribution and industrial layout of coal around the world are uneven, namely, production areas, reserve areas and consumption areas of coal are dislocated in space, so it is particularly important to have an excellent coal logistics network. Starting from the traditional genetic algorithm mechanism, aiming at the shortcomings of traditional genetic algorithm in solving problems of logistics transportation path optimization, such as precocity and insufficient local search ability, the paper proposes a hybrid genetic algorithm combining partheno-genetic algorithm and traditional genetic algorithm in genetic manipulations and optimizes it based on the original genetics. This algorithm not only retains the optimization strategy of finding new and better individuals through genetic cross-mutation inheritance in traditional genetic algorithms, but also introduces the evolutionary function that can perform single gene transposition and is suitable for combinatorial optimization problems in partheno-genetic algorithms. Through mathematical models, simulation experiments are conducted on the basis of actual transportation network data. The experimental results show that compared with the original genetic algorithm and the simple partheno-genetic algorithm, the hybrid genetic algorithm improves the global optimization ability and the convergence speed of the algorithm. Therefore, it is proved that the hybrid genetic algorithm is more effective and has better applicability in terms of optimization of logistics distribution route.*
Keywords: Coal transportation, Partheno-genetic, Hybrid genetic, Genetic operator

1. **Introduction.** Unlike ordinary transportation, coal transportation has a large amount of traffic and a long distance, but the route is relatively fixed. Compared to ordinary transportation, the timeliness requirements for coal transportation are not too high, Therefore, a long-distance and heavy-duty transportation method needs to be found. For example, rail and water transport are the best choices. As one of the three major characteristics of coal transportation in the world, "rail-water intermodal transport" has become an important means to effectively realize the seamless convergence of railways and waterway resources and rationally transport coal transportation resources. Faced with the constant adjustment of the transportation prices of railways and waterways, how to rationally allocate transport capacity, correctly select transport modes and optimize logistics networks are of great significance for energy companies to reduce logistics costs.

Through the research on the optimization of logistics and transportation, it has been found that the problem of transport routes and traffic volume is an NP (non-deterministic polynomial) complete problem [1]. In the early 1960s, the problem of transport routes has always been an important issue in the logistics field [2]. At present, there are many

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kinds of algorithms for transportation problems, including artificial bee colony algorithm (ABC) [3-6], tabu search method [7], genetic algorithm [8-10], heuristic algorithm, ant colony algorithm [11], etc. Among them, the genetic algorithm is an effective global search algorithm to solve this kind of NP complete problem, but there is the problem of premature and insufficient local search ability when solving the problem of vehicle routes. Therefore, to seek a reasonable method to improve the efficiency of the algorithm and enhance the optimization performance of the algorithm for the distribution vehicle scheduling has become the main content of relevant scholars [12].

With the idea of "survival of the fittest", the genetic algorithm [13] is an algorithm that searches for optimal solutions by simulating the evolutionary process of the natural world. This idea reveals a basic law of nature, that is, the species most suitable for the natural environment tend to produce larger groups and have the advantage of survival, but species that do not adapt to the natural environment will be eliminated. The genetic algorithm borrows from this law and simulates the natural evolution process through algorithms. Genetic algorithm has the advantages of robustness, globality, and implicit parallelism, which make it widely used. However, the genetic algorithm has a drawback that cannot be ignored. That is, in the course of evolutionary operations, the diversity of individuals within a group is reduced due to the effect of selection pressure, so that the solution of the genetic algorithm stays at a certain local optimal point, and the global optimal solution cannot be achieved. This is the so-called "premature convergence" phenomenon.

People have done a lot of work to prevent the "premature convergence" phenomenon of genetic algorithms, including the design of new genetic operators with global search capabilities, optimization of genetic control parameters, and improvement of the operation process of genetic algorithms. In 1993, Whitley proposed the cellular genetic algorithm [14]. Enrique introduced a real-coded cellular genetic algorithm and studied the performance of solving continuous optimization problems. The result is obviously better than other algorithms [15]. AL-Madi proposed a new structured population approach for genetic algorithm, based on the custom, behavior and pattern of human community [16]. Li and Tong proposed to overcome the "premature convergence" problem by constructing new genetic operators such as restoration, reconstruction and self-crossover, which is the so-called partheno-genetic algorithm [17]. In order to improve the local search ability of genetic algorithm and improve its "premature convergence" phenomenon, this paper introduces a partheno-genetic operation based on the traditional genetic algorithm for logistics transportation problems. The advantage is that all genetic operations are performed on the same chromosome, and the shift and transposition operators are used instead of the crossover operator of traditional genetic algorithm, so it is suitable for orderly combinatorial optimization problems. At the same time, it combines the basic bionic nature of genetic, it means that after the completion of standard inheritance, select excellent individuals for partheno operation to replace inferior individuals in order to complete population updating.

According to the mode and characteristics of coal transportation, we establish a mathematical model aiming at maximizing the profits of coal industry groups. Then we synthetically analyze the advantages and disadvantages of standard genetic algorithm (SGA) and partheno-genetic algorithm (PGA), and combine the two optimization methods to obtain a hybrid genetic algorithm. Finally, taking the transportation problem of a coal group as the background, collecting the relevant data, using the hybrid genetic algorithm to solve the calculation, the transportation route optimization solution aiming at maximizing profits is obtained, which proves the effectiveness of the hybrid genetic algorithm in solving this kind of coal transportation problem.

2. Mathematical Model for Optimization of Coal Logistics Transportation.

2.1. Problem description.

The establishment of an optimization model for coal logistics transportation not only considers the logistics costs in the coal logistics network, but also considers how to maximize the group's overall benefits on the basis of saving logistics costs. Based on the actual operation of a transportation group, this article has established a coal transportation model with multiple production sites, multiple demand sites, and multiple transportation modes. At the same time, taking into account the proportion of the Group's shareholdings in the subsidiaries, the Group's overall interests are ultimately determined by making decisions on the production volume of coal mines owned by the Group, the transportation volume of shipping companies, the choice of coal transportation methods, and the method and quantity of coal purchased by power plants.

The realization of the optimization of the structure of the coal logistics network is the primary goal of the coal logistics network design. Therefore, the following factors that may affect the coal logistics network structure should be considered, including:

- *Quantity and price of coal commodity;*
- *Coal production sites and geographical distribution of power plants;*
- *The amount of coal required by power plants;*
- *The maximum capacity limit for railways and ports;*
- *Transportation costs of transport modes;*
- *The fixed cost of the operation of links;*
- *The proportion of shares of the Group in coal mines, power plants, shipping, and ports.*

2.2. Model assumptions and model symbols.

The model adopts the transport mode of "rail-water intermodal transport", which not only protects the rational allocation and utilization of natural resources, protects the natural environment, but also saves costs and increases corporate profits.

The following assumptions can be made through the description of coal logistics network problems:

1) The coal purchased from the power plants studied by the model comes from coal mines inside and outside the Group, and the output can fully meet the needs of the power plant;

2) Coal transportation methods include nonstop railway transportation and rail-sea intermodal transport;

3) In the transportation process, when coal passes through individual railway sections, the capacity is limited, and the throughput of the port is limited;

4) When rail-sea intermodal transport is selected as the mode of transportation, the sea cargo is divided into two alternative modes: the shipping company within Group and the shipping company outside Group;

5) The shipping capacity of group-owned shipping companies and external shipping companies is not limited;

6) In the rail-water intermodal transportation, the transshipment cost between railway and waterway is not counted, and there is no transportation process between power plant and water outlet.

The roadmap for the mode of transportation is shown in Figure 1.

Based on the above assumptions, an optimization model for coal logistics transportation is established. The relevant mathematical symbols are defined as follows:

i: represents coal mine, when $i = 1, 2, \ldots, k, k+1, \ldots, I$ ($i = 1, 2, \ldots, k-1$, it represents coal mines within the Group, when $i = k, k+1, \ldots, I$, it represents coal mines outside the Group);

j: represents the power plants within the Group, $j = 1, 2, \ldots, J$;

α_j: indicates the power generation efficiency (power generation efficiency refers to how much electricity can be generated with 1 ton of standard coal) of the power plant j within the Group, $j = 1, 2, \ldots, J$;

a: represents the inlet port, $a = 1, 2, \ldots, A$;

b: represents the outlet port, $b = 1, 2, \ldots, B$;

l: represents the transportation mode, ($l = 1$ represents the transportation mode of the nonstop railways, $l = 2$ represents the mode of transportation of railways and shipping companies within the Group, $l = 3$ represents the mode of transportation of railways and shipping companies outside the Group);

Q_i: represents the annual production of coal in coal mine i;

D_j: represents the annual demand of coal on power plant j;

x_{ijl} indicates the traffic volume of coal from the coal mine i to the power plant j via the mode of transport l;

In it:

when $l = 1$, x_{ij1} represents transport volume of coal from coal mine i to power plant j via the nonstop railway mode;

when $l = 2$, x_{ij2}^{ab} represents transport volume of coal from coal mine i to power plant j via railway and the water route in the transportation mode of the Shipping Conpany within Group from the inlet port a to the port of expert b;

when $l = 3$, x_{ij3}^{ab} represents transport volume of coal from coal mine i to power plant j via railway and the water route in the transportation mode of the Shipping Conpany outside Group from the inlet port a to the port of expert b;

M_{ij}: represents the maximum transport volumes of coal from coal mine i to power plant j;

M_a: represents the maximum throughputs of the inlet port a of coal from the coal mine i to the power plant j via shipping;

M_b: represents the maximum throughputs of the inlet port b of coal from the coal mine i to the power plant j via shipping;

c_{ij}: represents the unit transportation cost (yuan/(t×km)) of railway from coal mine i to power plant j via the transportation mode of nonstop railway;

c_i^a: represents the unit transportation cost (yuan/(t×km)) of railway from coal mine i to inlet port a (The location of all power plants is considered to be the location of the outlet port b, so there is no c_i^b.);

c_1^{ab}: represents the unit transportation cost (yuan/ton×nautical miles) of when choosing rail-water intermodal transport and using the water transportation of internal shipping company from inlet port a to outlet port b;

L_{ij}: represents the transportation distance (km) of the railway line from the coal mine i to the power plant j via the transportation mode of nonstop railway;

L_i^a: represents the transportation distance (km) of the railway line from the coal mine i to the inlet port a via the rail-water intermodal transport;

L_{ab}: represents the water transport distance (nautical miles) from the inlet port a to the outlet port b;

c_a^1: represents the unit operating cost of the port in the process of the transfer inlet port a (yuan/ton);

c_b^2: represents the unit operating cost of the port in the process of the transfer of outlet port b (yuan/ton);

p_a^1: represents the unit service cost of the port in the process of the transfer of inlet port a (yuan/ton);

p_b^2: represents the unit service cost of the port in the process of the transfer of outlet port b (yuan/ton);

c_i^3: represent the mine-mouth coal costs in coal mine i;

p_i^3: represent the mine-mouth coal prices in coal mine i;

p_1^{ab}: represents the unit transportation price of the internal shipping company's water transportation from the inlet port a to the outlet port b (yuan/(ton×nautical miles));

p_2^{ab}: represents the unit transportation price of the external shipping company's water transportation from the inlet inlet port a to the outlet port b (yuan/(ton×nautical miles));

p_j: represents the electricity price per kWh of the plant j;

F_a^1: represents the fixed cost of operation of the inlet port a;

F_b^2: represents the fixed cost of operation of the outlet port b;

F_i^3: represents the fixed cost of coal mine i operation $(i = 1, 2, \ldots, k-1)$;

F_j^4: represents the fixed costs of the operation of the power plant j;

F^5: represents the fixed costs of the operation of the Group's shipping companies;

R_i^1: represents the proportion of shares of the group in the coal mine i $(i = 1, 2, \ldots, k-1)$;

R_j^2: represents the proportion of the company's shares in power plant j;

R_a^3: represents the proportion of the group's share in the inlet port a;

R_b^4: represents the proportion of the group's share in the outlet port b;

R^5: represents the proportion of the company's shares in the shipping company;

Note: The annual production volume of coal mines, the annual demand of power plants, the throughput of ports, and the rail transportation are in tons.

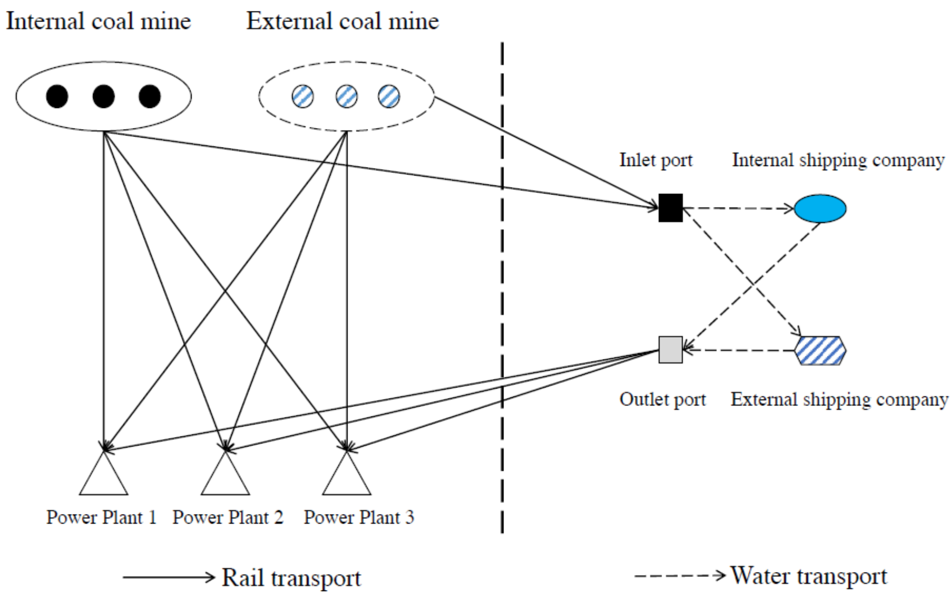

FIGURE 1. Transportation route map

2.3. **Modeling.** With the goal of maximizing the profit of a coal group, the model carries out optimizing and solving, and the objective function and constraints are as follows:

1) Profit of coal mines i within the group:

$$W_i = \left(p_i^3 - c_i^3\right) \sum_{j=1}^{J} \sum_{l=1}^{3} x_{ijl} - F_i^3$$

$$x_{ij2} = \sum_{a=1}^{A}\sum_{b=1}^{B} x_{ij2}^{ab}$$

$$x_{ij3} = \sum_{a=1}^{A}\sum_{b=1}^{B} x_{ij3}^{ab}$$

2) The profit of power plant j:

$$W_j = \alpha_j p_j \sum_{i=1}^{I}\sum_{l=1}^{3} x_{ijl} - C_j^1 - C_j^2 - C_j^3 - C_j^4 - F_j^4$$

Therein:

1) Railway transportation costs C_j^1 paid by power plant j:

$$C_j^1 = \sum_{i=1}^{I} (x_{ij1} L_{ij} c_{ij}) + \sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{i=1}^{I} \left(x_{ij2}^{ab} c_i^a L_i^a\right) + \sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{i=1}^{I} \left(x_{ij3}^{ab} c_i^a L_i^a\right)$$

2) The cost C_j^2 of the coal purchased by the power plant j:

$$C_j^2 = \sum_{i=1}^{I}\sum_{l=1}^{3} \left(p_i^3 x_{ijl}\right)$$

3) Transportation costs C_j^3 of the external shipping company paid by the power plant j:

$$C_j^3 = \sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{i=1}^{I} \left(p_2^{ab} L_{ab} x_{ij3}^{ab}\right)$$

4) The transportation costs C_j^4 of the internal shipping company paid by the power plant j:

$$C_j^4 = \sum_{a=1}^{A}\sum_{b=1}^{B}\sum_{i=1}^{I} \left(p_1^{ab} L_{ab} x_{ij2}^{ab}\right)$$

5) Transshipment profits of inlet port a:

$$W_a = \left(p_a^1 - c_a^1\right) \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{b=1}^{B} \left(x_{ij2}^{ab} + x_{ij3}^{ab}\right) - F_a^1$$

6) Transshipment profits of outlet port b:

$$W_b = \left(p_b^2 - c_b^2\right) \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{a=1}^{A} \left(x_{ij2}^{ab} + x_{ij3}^{ab}\right) - F_b^2$$

7) Freight revenue of internal shipping companies:

$$W_s = \sum_{a=1}^{A}\sum_{b=1}^{B} \left[\left(p_1^{ab} - c_1^{ab}\right) \left(\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij2}^{ab}\right) L_{ab}\right] - F^5$$

Objective function:

$$W = Max \left(\sum_{i=1}^{k} R_i^1 W_i + \sum_{j=1}^{J} R_j^2 W_j + \sum_{a=1}^{A} R_a^3 W_a + \sum_{b=1}^{B} R_b^4 W_b + R^5 W_s\right)$$

The objective function represents the total profit of the group.

Subject to:

1) The minimum coal demand to meet the power plant j:

$$\sum_{i=1}^{I} Q_i \geq \sum_{j=1}^{J} D_j$$

It means that the demand of power plants can be met.

2) The maximum capacity of the selected route for rail transport:

$$x_{ij1} \leq M_{ij}$$

It means that the demand for coal transportation in railway transportation cannot exceed the maximum capacity of railway transportation.

3) The maximum throughput of inlet port a cannot be exceeded:

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{b=1}^{B} \left(x_{ij2}^{ab} + x_{ij3}^{ab}\right) \leq M_a$$

It means that in the rail-water intermodal transportation, the amount of coal transported into the port should not exceed the maximum throughput of the port.

4) The maximum throughput of outlet port b cannot be exceeded:

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{a=1}^{A} \left(x_{ij2}^{ab} + x_{ij3}^{ab}\right) \leq M_b$$

It means that the coal transportation through the outlet port cannot exceed the maximum throughput of the port in the rail-water intermodal transportation.

5) The proportion of the company's shares in each company:

$$0 \leq \left(R_i^1, R_j^2, R_a^3, R_b^4, R^5\right) \leq 1$$

In it:

W: represents the total profit of the company;

W_i: represents the profit of the coal mine i within the group;

W_j: represents the profit of the Group's power plant j;

W_a: represents the profit of the inlet port a;

W_b: represents the profit of the outlet port b;

W_s: represents the profit of the shipping company;

C_j^1: represents the railway transportation costs paid by the power plant j;

C_j^2: represents the cost of the coal purchased by the power plant j;

C_j^3: represents the transportation costs of the external shipping company paid by the power plant j;

C_j^4: represents the transportation costs of the internal shipping company paid by the power plant j.

3. **Hybrid Genetic Algorithm for Coal Transportation Optimization Model.** The traditional standard genetic algorithm is based on the Bionics Principles to optimize and solve, and it can exert the superiority of the parental individual very well. However, for the requirement of the initial population in number, it is easy to "premature convergence" when the parental individual is the same. Therefore, based on the traditional genetic algorithm, this paper further optimizes the optimized individuals in the offspring, and adopts partheno-genetic operations to update the offspring individuals with poor target values. This can not only retain the good individuals in the offspring, but also further optimize the fitness of offspring.

3.1. Standard genetic algorithm.

Genetic algorithm has the advantages of robustness, globality, and implicit parallelism, which make it widely used. The design of genetic algorithms mainly includes the following aspects.

1) Solution encoding and decoding.

The structure of many application problems is complex, but it can be translated into simple bit strings. The process of transforming a problem structure into a bit string is called coding; conversely, the process of transforming a bit string form into the original problem structure is called decoding. The bit string in the above process is usually called a chromosome (individual).

2) Determination of initial population and size.

The initial population is generally selected at random or it is generated by some heuristic method. The initial population was randomly selected and iterated through genetic manipulations to traverse all states, thus allowing the optimal solution to survive in the evolution of genetic algorithms.

3) Determination of fitness function.

In order to reflect the adaptability of chromosomes, a function that can measure each chromosome in the problem is introduced, called the fitness function.

4) Genetic operators.

When searching for the optimal solution, the genetic algorithm searches the solution space through the extension of the genetic operator. Operators of basic genetic algorithms include selection (replication) operators, crossover operators, and mutation operators.

3.2. Parthenon-genetic algorithm.

The genetic operators of parthenon-genetic algorithm (PGA) are selective, gene recombination and gene mutation, among which the selection operator is basically the same as the operator of traditional genetic algorithm. The genetic operations of the parthenon-genetic algorithm are all performed on one chromosome. Compared with the traditional genetic algorithm, the offspring individual of the parthenon-genetic algorithm inherits most of the genetic characteristics of the parental individual, and there is no phenomenon of premature convergence. Even if all individuals in the population are the same, genetic operations can be performed and it is easy to handle constraints that constrain the optimization problem.

A single parent genetic algorithm is a genetic method that uses selection, gene transposition, gene shifting, and gene inversion to propagate offspring. Among them, the operator of gene transposition is a process of exchanging genes at certain positions in a chromosome with a certain probability Pe, and the positions of the exchanged genes are random. Gene transposition can be divided into single-point transposition and multi-point transposition. Single-point transposition only exchanges one pair (two) genes at a time; the multi-point transposition takes a random number i ($1 \leq i \leq Ue$) to exchange i pairs of genes at a time for a predetermined positive integer Ue. Single-point transposition is also called mutation operator. Since the encoding method is natural number encoding, duplicate numbers are not allowed. The method of transposition is to change one gene position while changing another gene position with the same sequence number. The operation process is shown in Figure 2.

The operator of gene shifting shifts the genes in some substrings of a chromosome backwards, with a certain probability Ps, and shifts the last gene of the substring to the frontmost position. The substring and its length of the gene shifting on a chromosome are randomly selected. Gene shifting can be divided into single-point shifting and multi-point shifting. Single-point shifting is to take only one substring in a chromosome to perform a operation of gene shifting; Multi-point shifting is to take a random number j ($1 \leq j \leq Us$), and take j sub-strings in one chromosome to perform a operation of

$$\text{A}=(c_1, c_2, c_3, \ldots, c_{i-1} c_i c_{i+1}, \ldots, c_{j-1} c_j c_{j+1}, \ldots, c_n)$$

$$\Downarrow$$

$$\text{B}=(c_1, c_2, c_3, \ldots, c_{i-1} c_j c_{i+1}, \ldots, c_{j-1} c_i c_{j+1}, \ldots, c_n)$$

FIGURE 2. The operation of single-point transposition

gene shifting for a predetermined positive integer. The shifting operation must satisfy a constraint that the shift operation cannot cause the capacity of the new parental node to overflow. The operation of single-point shifting is shown in Figure 3.

$$\text{A}=(c_1, c_2, c_3, \ldots, c_{i-1} c_i c_{i+1}, \ldots, c_{j-1} c_j c_{j+1}, \ldots, c_n)$$

$$\Downarrow$$

$$\text{B}=(c_1, c_2, c_3, \ldots, c_{i-1} c_j c_i c_{i+1}, \ldots, c_{j-1} c_{j+1}, \ldots, c_n)$$

FIGURE 3. The operation of single-point shifting

The operator of gene inversion reverses the genes in some substrings of a chromosome, with a certain probability Pi, and the substrings and lengths of the gene inversion in one chromosome are randomly selected. Gene inversion can be divided into single-point inversion and multi-point inversion. Single-point inversion is to take only one substring in a chromosome to perform gene inversion; the multi-point inversion is to take a random number j $(1 \leq j \leq Uj)$ and take j sub-strings in one chromosome to perform a gene inversion operation for a predetermined positive integer Uj. The inversion operator does not need to determine the capacity overflow of the parental node. The operation is shown in Figure 4.

$$\text{A}=(c_1, c_2, c_3, \ldots, c_{i-1} c_i c_{i+1}, \ldots, c_{j-1} c_j c_{j+1}, \ldots, c_n)$$

$$\Downarrow$$

$$\text{B}=(c_1, c_2, c_3, \ldots, c_{i-1} c_j c_{j-1}, \ldots, c_{i+1} c_i c_{j+1}, \ldots, c_n)$$

FIGURE 4. The operation of single-point inversion

Multi-point genetic operators are generally used when the chromosome length l is large, while single-point genetic operators are generally used when the chromosome length is small.

3.3. **Hybrid genetic algorithm.** The hybrid genetic algorithm mainly performs the mixing on the processing of genetic operators. This not only retains the traditional bionic genetic operation, that is, the generation of offspring is through the parent's cross-compilation, but also in the offspring of good individuals to perform further parthenon-genetic operations, to avoid falling into premature convergence.

1) Encoding and decoding. The encoding process is a process of using numbers to express the traffic volume of each route. Due to the need to solve the specific traffic volume for each route, binary encoding is used. This article uses 10-bit binary encoding,

12 lines, that is, 120-bit binary encoding. After the encoding is completed, according to the total demand of each power plant, binary-to-decimal values are manipulated to distribute the proportion of traffic on the line. In other words, the traffic volume on each route can be counted, and the corresponding fees and profits can be obtained.

2) Determination of initial population and size. Traditional genetic algorithms tend to fall into a local optimum when the population size is small, but the introduction of a parthenon-genetic in traditional operation can effectively avoid this problem. Therefore, the number of populations in this paper is set to 60.

3) Fitness function. With the objective of maximizing the profit of the Group company, this paper optimizes the transportation routes and traffic volume. At the same time, considering the constraint conditions, when dealing with the constraint problem, this article quantifies the violation of the constraint, and quantifies the combination of the penalty function and the objective function into a fitness function.

4) Selection. The selection in this article uses an elite retention strategy. Adopting this strategy in the traditional algorithm is easy to lose the diversity of the population, but it can be well avoided by combining parthenon-genetic operation, and the operation is simple, and the diversity of the population is not lost.

5) Genetic operators. In genetic manipulation, the first is the traditional crossover of individuals in a population to generate offspring and offspring mutation operations, and then combine the offspring population with the parental population to form a new population. Based on the limit of population size, populations with better fitness are selected to form new offspring populations. Next, according to the parthenon-genetic strategy, after excellent individuals transpose, shift, and invert non-excellent individuals in the offspring population, new individuals are created to replace and update the population.

The algorithm is coded as follows:

```
Initial population
  For each h in population, compute Fitness (h)
    While (iter < maxiter)
      do SGA (do crossover, do mutation, do selection)
      do PGA (do transpose, do shift, do invert)
    update population
    End
  For each h in population, compute Fitness (h)
Return best Fitness
```

The algorithm flowchart is shown in Figure 5.

4. **Model Solving and Data Analysis.**

4.1. **Preparation of examples and data.**

As China's main energy source, the coal industry is an important basic industry that is related to the sustained, stable, and healthy development of Chinese economy. With the acceleration of the construction of large-scale coal bases in China, large-scale coal enterprise groups have developed rapidly, and large-scale modern coal capacity has been continuously released. Driven by market demand, in general, the production of coal has maintained rapid growth. In 2017, the coal output of large-scale and above coal enterprises reached 3.445 billion tons, a year-on-year increase of 3.2%.

Because coal occupies a dominant position in production and consumption structure of China's energy sources, the imbalance of geographical distribution and industrial layout of China's coal results in a large amount of coal flowing from west to east and from north to south within the Chinese territory, thus meeting the demand for coal in various

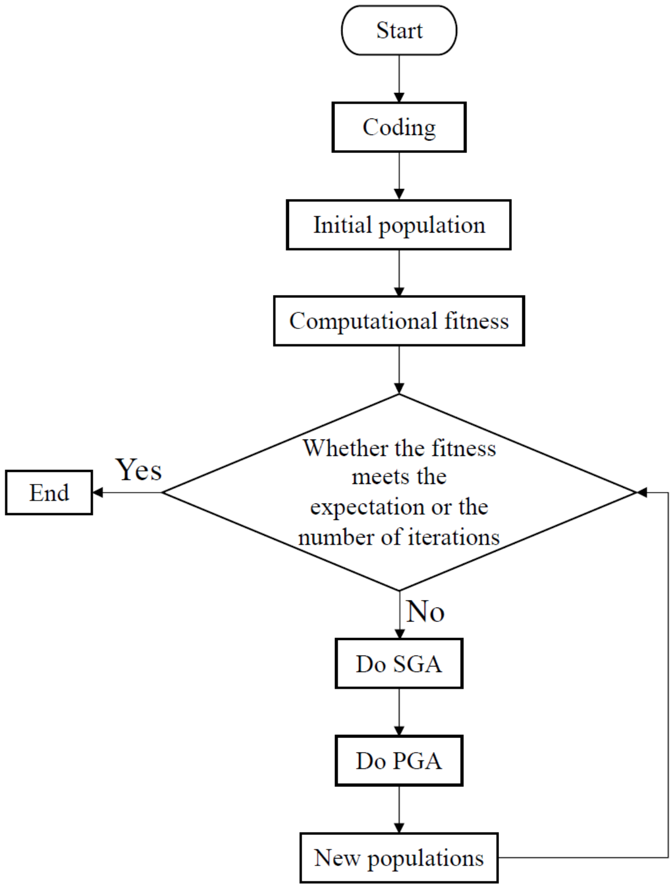

FIGURE 5. The algorithm flowchart

regions and industries. Therefore, the transport link plays a very important role in the coal circulation process, has become the key to achieving the balance between supply and demand of coal, and is one of the main factors affecting the balance of the coal market.

1) Coal mines and power plants.

The three coal mines of a coal industry group in China were selected, which are located in Shanxi (M1), Shaanxi (M2) and western Inner Mongolia (M3). Two coal mines outside the group were selected, located in Henan (M4) and Shanxi (M5) respectively. The power plants were selected as Yangluo Power Plant (E1) (Wuhan, Hubei), Qinbei Power Plant (E2) (Jiyuan, Henan) and Yingkou Power Plant (E3) (Yingkou, Liaoning). As an inland power plant, Yangluo Power Plant can directly transport coal from coal mines to power plants via railways and can also use rail-sea transport. At the same time, Yangluo Power Plant can also enter the inland river through the coastal ports to transport coal by means of sea-to-river transport. As Qinbei Power Plant is located near Shanxi Province and Shaanxi Province where coal reserves are relatively large, its main mode of transportation is nonstop railway. Yingkou Power Plant is a coastal power plant. After the coal was first transported by railway or highway to a coastal port, it used coastal vessels to transport the coal to the power plant. Its electricity-coal industry mainly relies on domestic railway-sea transport.

Shanxi's coal is mainly transported through Daqin (R1), Zhangtang (R2), Taijiao (R3), Jiaoliu (R4) and Hantan (R5), mainly to Beijing, Tianjin, Hebei, East China and coastal ports; Shaanxi's coal is mainly transported through Xikang (R6), Xiangyu (R7), Hantan, Longhai (R8) and Jiaoliu Railway, mainly to Beijing, Tianjin, Hebei, East China and coastal ports; Coal from Mengxi is mainly transported by Beijing-Baotou (R9), Datong-Zhungeer (R10), Hubin-Daan (R11), Daqin-Hudong (R12), Wulanchabu-Baotou (R13) and Baotou-Caofeidian (R14) railways, mainly to Beijing-Tianjin-Hebei, north-east and coastal ports, and also to Beijing-Guangzhou (R15), Mengmiao Station-Baofeng Pingdingshan (R16), Houma-Yueshan (R17) and Shenchinan. Shenchi-Huanghua Port (R18) railways are mostly used for coal transportation, including Qinhuangdao Port (P1) and Yingkou Port (P2), Caofeidian Port (P3), Huanghua Port (P4), Taicang Port (P5). This model assumes that the specific route from the coal mine to the power plant is as follows (The entire route is fixed, and it uses the model to select the route and the amount of traffic on this route).

Table 1. Transport routes in model

	M1	M2	M3	M4	M5
E1	R3-R4-R5	R6-R7-R5	R9-R10-R11-R1-P1-P5	R15	
E2	R3-R4	R6-R7-R5		R15-R4	R17
E3	R1-P1-P2	R1-R2-P3-P2	R12-R13-R14-P3-P2		R18-P4-P2

A total of five coal mines were selected, of which three were coal mines within the group and the other two were coal mines outside the group.

Table 2. Data for coal mines

	Coals within the Group			Coals outside the Group	
Coal origin i	M1	M2	M3	M4	M5
Annual output Q_i	4900000	4000000	3000000	1800000	2800000
Mine-mouth coal prices P_i^3	680	624	590	696	660
Mine-mouth coal costs C_i^3	510	518	460	540	522
Stock's proportion R_i^1	50%	30%	70%	45%	65%

The annual output Q_i of coal mines is in tons, and the mine-mouth coal price and mine-mouth coal cost is in yuan. The difference value represents the profit earned by coal mine that sells a ton of coal. The profit of a coal mine W_i consists of the difference between the total profit of selling coal and the fixed cost of a coal mine. Next, $i = 1, 2, 3, 4, 5$ represent Shanxi Coal Mine, Shaanxi Coal Mine and Coal Mine of West of Inner Mongolia in the Group, Henan Coal Mine and Shanxi Coal Mine outside the Group.

Table 3. Data for power plant

Power plant j	E1	E2	E3
Annual demand D_j	2890000	7930000	5000000
Electricity price P_j	1.3	1.1	0.9
Fixed cost F_j^4	870000	930000	1250000
Generating efficiency α_j	2300	2280	2150
Stock's proportion R_j^2	75%	60%	100%

The annual demand D_j for power plants is in tons, Electricity prices and fixed costs are in yuan, and power plant profit $W_j = \alpha_j p_j \sum_{i=1}^{I} \sum_{l=1}^{3} x_{ijl} - C_j^1 - C_j^2 - C_j^3 - C_j^4 - F_j^4$ is divided into two parts: income and fees. The source of revenue for the power plant and the fees charged by the users charged. The fees include the railway transportation cost of the power plant, the cost of purchasing the coal, the transportation cost of the shipping company, and the fixed cost (not directly related to electricity production, including material costs, wages, depreciation, maintenance, etc.).

TABLE 4. Maximum capacity of railway lines from coal mines to power plants (unit: ton)

j \ i	M1	M2	M3	M4	M5
E1	2780000	1916000	1340000	1220000	1257000
E2	2300000	1290000	1650000	1426465	2880000
E3	2902700	1483000	3147000	2810000	1390600

2) Data for nonstop railway

Since the number of power plants involved in the model is only three, the maximum traffic volume of railway lines has been reduced.

$$\text{The maximum traffic volume of railway in the model} = \frac{\text{The maximum traffic volume of railway}}{\text{Coal demand of all power plants in the group}} * \text{Coal demand for power plants in the model}$$

TABLE 5. Unit transportation cost of railways from coal mines to power plants through the transportation of nonstop railway (unit: yuan/(tons×km))

j \ i	M1	M2	M3	M4	M5
E1	0.98	0.88	–	1.17	–
E2	1.03	0.92	–	1.10	0.78
E3	–	–	–	–	–

Note: "–" means non-railway nonstop routes, so there is no value (the same below).

TABLE 6. Transportation distance of railways from coal mines to power plants through the transportation of nonstop railway (unit: km)

j \ i	M1	M2	M3	M4	M5
E1	1500	884	–	632	–
E2	623	478	–	236	231
E3	–	–	–	–	–

The ports of $a = 1, 2, 3$ entry represent Qinhuangdao Port, Caofeidian Port and Huanghua Port respectively. The ports of $b = 1, 2$ export represent Yingkou Port and Taicang Port respectively. The maximum throughput was reduced in proportion based on the total demand of the all power plants in the Group and the total demand of three power plants studied in models.

4.2. **Parameter settings.** According to the above model and optimization method, in the process of using Matlab-R2016b to solve the algorithm, the crossover probability is 0.9, the mutation probability is 0.1, the population size is taken as 60, and the genetic algebraicity is 100, to write a program for algorithm solving.

Table 7. Maximum throughput of inlet port (unit: ton)

a	P1	P3	P4
M_a	8000000	2250000	4000000

Table 8. Maximum throughput of outlet port (unit: ton)

b	P2	P5
M_b	5800000	1800000

Table 9. Unit transportation costs for railroads from coal mines to ports of entry via rail-water intermodal transport (unit: yuan/ton×km)

a \ i	M1	M2	M3	M4	M5
P1	1.21	–	1.02	–	–
P3	1.08	–	0.98	–	–
P4	–	–	–	–	1.1

Table 10. Transportation distances of railway lines from coal mines to ports of entry via rail-water intermodal transport (unit: km)

a \ i	M1	M2	M3	M4	M5
P1	644	–	1123	–	–
P3	688	–	1075	–	–
P4	–	–	–	–	598

Table 11. Unit shipping price of water transportation from the inlet port to the outlet port by an internal shipping company (yuan/(ton×nautical miles))

b \ a	P1	P3	P4
P2	0.34	0.27	0.32
P5	0.28	0.36	0.26

Table 12. Unit shipping price of water transportation from the inlet port to the outlet port by an external shipping company (yuan/(ton×nautical miles))

b \ a	P1	P3	P4
P2	0.31	0.33	0.29
P5	0.38	0.34	0.27

Table 13. Data of shipping company

Fixed costs F_5	Stock's proportion R_5
880000	100%

TABLE 14. Data of the inlet port

a	C_a^1	P_b^1	F_a^1	R_a^3
P1	23.5	28	850000	50%
P3	20.5	31	680000	100%
P4	21.6	27.6	730000	30%

TABLE 15. Data of the outlet port

b	C_b^1	P_b^2	F_b^2	R_b^4
P2	27	32	720000	60%
P5	35	40.5	540000	80%

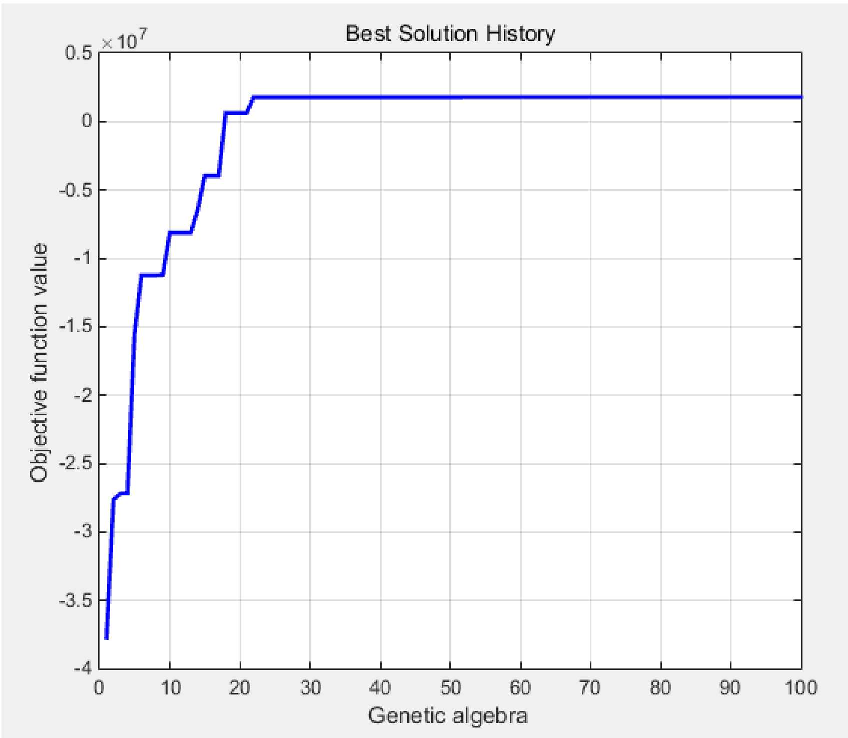

FIGURE 6. Standard genetic algorithm changing curve of total profit with the genetic algebra

4.3. **Results of the test.** Figure 6, Figure 7, and Figure 8 respectively show the changing curves of the function values of the fitness with the genetic algebra in the standard genetic algorithm, partheno-genetic algorithm, and the hybrid genetic algorithm. As can be seen from the figure, the fitness function is negative in the initial population. This shows that under the initial conditions, the constraint condition is not satisfied, and as the genetic operation progresses, the fitness function gradually increases, the penalty terms of the constraint condition gradually increase, and the profit value gradually increases. Finally, they gradually converge to a certain value, indicating the effectiveness and convergence of the algorithm.

In the three genetic algorithms, the standard genetic algorithm starts to converge at the 36th algebra, the partheno-genetic algorithm starts to converge at the 32nd algebra, and the hybrid genetic algorithm converges at the 12th algebra, indicating that the hybrid genetic algorithm has a good advantage in solving the transportation problem, and its

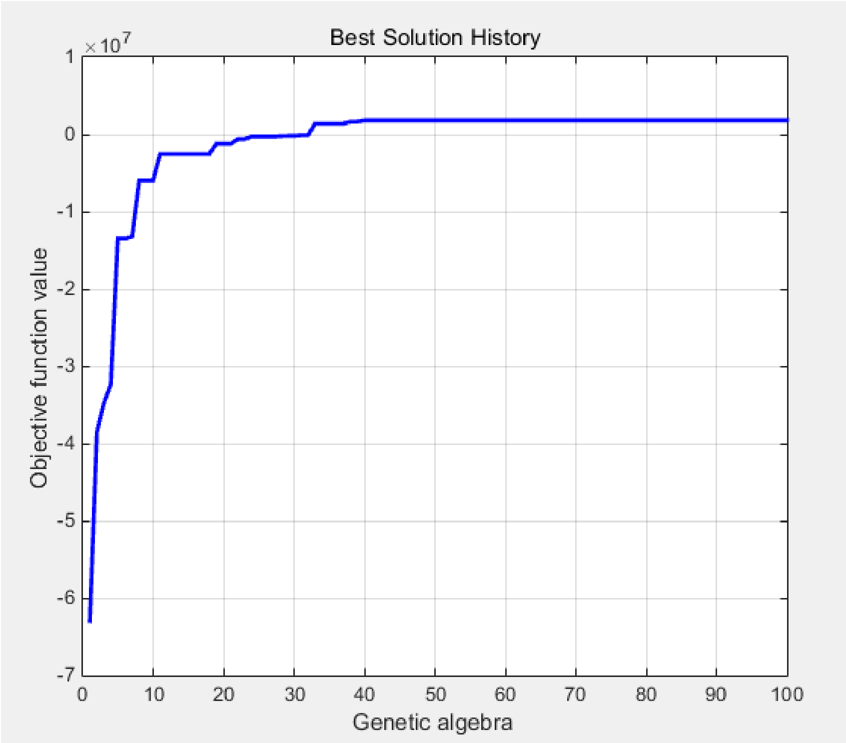

FIGURE 7. Partheno-genetic algorithm changing curve of total profit with the genetic algebra

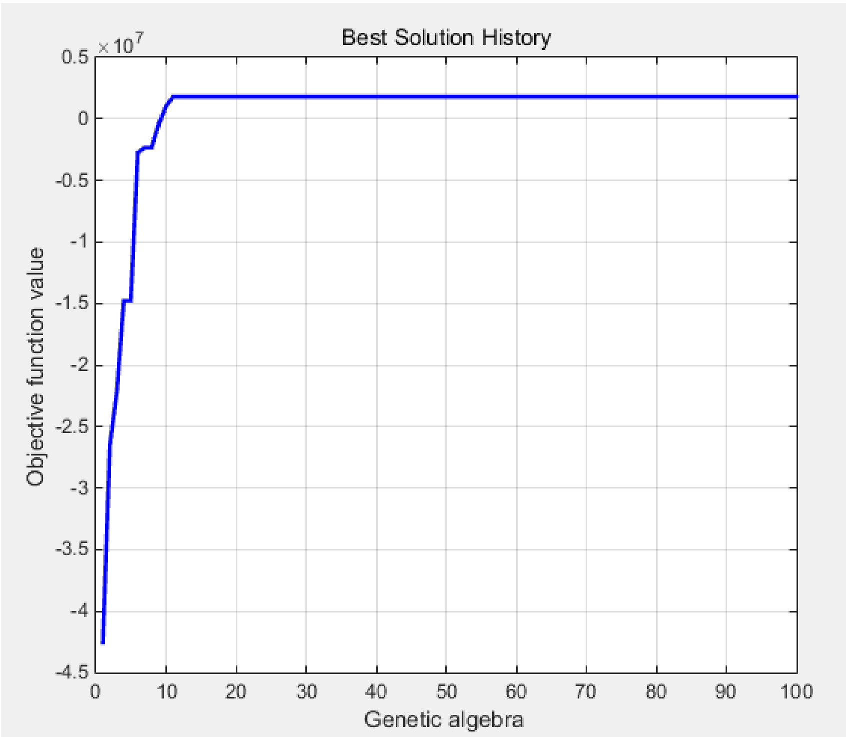

FIGURE 8. Hybrid genetic algorithm changing curve of total profit with the genetic algebra

convergence speed is very fast. Table 16, Table 17 and Table 18 show the actual route traffic volume obtained by the three genetic algorithms. Table 19 shows the profit value. It can be shown from Table 19 that the hybrid genetic algorithm can find the optimal solution better. The comprehensive results show that the hybrid genetic algorithm has a good applicability in solving such transportation problems.

TABLE 16. Standard genetic algorithm model transport lines and volumes

(ten thousand tons)	M1	M2	M3	M4 (outside the group)	M5 (outside the group)
E1	35	102	97	54	–
E2	229	197	–	191	176
E3	148 106	–	122	–	124

TABLE 17. Partheno-genetic algorithm model transport lines and volumes

(ten thousand tons)	M1	M2	M3	M4 (outside the group)	M5 (outside the group)
E1	93	72	68	57	–
E2	142	224	–	239	188
E3	113 166	–	110	–	111

TABLE 18. Hybrid genetic algorithm model transport lines and volumes

(ten thousand tons)	M1	M2	M3	M4 (outside the group)	M5 (outside the group)
E1	23	15	129	22	–
E2	199	185	–	224	184
E3	122 163	–	103	–	112

TABLE 19. Three genetic algorithms model transport lines and volumes

Genetic algorithm	Standard genetic algorithm	Partheno-genetic algorithm	Hybrid genetic algorithm
Total profit (ten thousand yuan)	165	150	180

Standard genetic algorithm optimizes quickly before the 10th generation, the optimization rate decreases gradually after the 10th generation. Partheno-genetic algorithm optimizes quickly before the 10th generation, and the optimization result is better than standard genetic algorithm. However, after the 10th generation, the optimization rate decreases more than standard genetic algorithm, the optimization effect is not obvious. Hybrid genetic algorithm completely overcomes the previous optimization effect, with the genetic algebra. The problem of increasing and decreasing optimization speed has reached the optimal solution in about 10 generations, and the optimization effect is better than the former two methods, which shows that the hybrid genetic algorithm has better optimization performance.

From the above table, it can be seen that the difference of coal quantity between railway transportation and intermodal transport is not nearly equal, which indicates that waterway transportation plays a very important role in heavy cargo transportation. At the same time, many railway lines bear very few transportation tasks, and the cost of railway construction is high. Therefore, it is particularly important to plan railway construction reasonably, and at the same time, to develop multimodal transport. Under the international background of intermodal transport, waterway transport will undertake more and more transportation tasks, and transport costs and time will be better optimized. The optimization results can provide good guidance for coal transport enterprises to formulate transport strategies.

The results show that the hybrid genetic algorithm has good applicability and validity in solving such transportation problems.

5. **Conclusion.** Combining with the coal transportation problem of a group company, this paper establishes a mathematical model for profit maximization. Based on the traditional genetic algorithm, this paper combines the constraint conditions, and adopts the operating mode of genetic operator mixed with partheno-genetic algorithm to carry out the model solving, which not only avoids premature problems, it also improves the speed of convergence and the ability to find global optimums. Through the simulation analysis of the actual data, compared with the traditional genetic algorithm and the partheno-genetic algorithm, the hybrid genetic algorithm has excellent applicability and effectiveness for solving such problems. The result of the solution can provide a reference for the company to develop a transportation scheme, and this solution can be used in more complex transportation problems to further optimize the algorithm.

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