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Research on multi-target routing problem of coal emergency logistics vehicles based on genetic algorithm

The existing studies on the routing problem of emergency logistics vehicles emphasize on qualitative analysis over quantitative research. To solve the problem, this paper combines qualitative and quantitative methods into a mathematical model of the routing problem, and adopts the genetic algorithm (GA) to enhance the transport efficiency and reduce the accident loss. Due to the lack of research on the maximum number of iterations, control parameters, etc., the rationality of the proposed iteration number and parameters was tested through a case simulation on Matlab R2011b. Through repeated tests, it is proved that the GA, the maximum number of iterations and the control parameters can find the optimal solution for the routing problem and achieve the desirable effect. In addition, the authors discussed the impacts of different crossover probabilities and mutation probabilities on the solution time and accuracy. This research provides strong supports to emergency management agencies in transport route design, allocation of relief items, manpower and vehicles, and reduction of disaster loss.

Keywords: *Coal emergency logistics vehicles, genetic algorithm (GA), routing problem, maximum number of iterations, control parameters.*

1. Introduction

As an important pillar of energy in China, the coal industry has played a very important role in promoting the development of country's economy. At the same time, the coal industry is also the most frequently occurring industry. It not only seriously endangers the national property and life safety, but also damages the image of the country [1].

Recent years has witnessed frequent coal disasters in China, causing great damages and negative repercussions [2]. This calls for a time- and cost-saving plan to deploy a vast amount of emergency and first-aid items to the stricken area via the limited transport facilities and the optimal transport route. Therefore, this paper explores the routing problem of coal emergency logistics vehicles (hereinafter referred to as the routing problem), aiming to alleviate coal disaster loss, promote coal post-disaster restoration, and facilitate coal emergency management.

The existing studies on the routing problem emphasize on qualitative analysis over quantitative research. To solve the problem, this paper combines qualitative and quantitative methods into a mathematical model of the routing problem, and adopts the genetic algorithm (GA) to enhance the transport efficiency and reduce the coal accident loss. Due to the lack of research on the maximum number of iterations, control parameters, etc., the rationality of the proposed iteration number and parameters was tested through a case simulation on Matlab R2011b. Through repeated tests, it is proved that the GA, inspired by the process of natural selection, can find the optimal solution for the routing problem and achieve the desirable effect. This research provides strong supports to coal emergency management agencies in transport route design, allocation of relief items, manpower and vehicles, and reduction of coal disaster loss.

2. Overview of the routing problem

Coal emergency logistics refers to the logistics organized for transporting relief items from the supply point to demand point during emergencies like coal disasters[3]. It involves the processing of relevant information, and the collection, transport, storage, packaging, distribution and recycling of relief items [4]. The purpose of coal emergency logistics is to minimize coal disaster damages in the shortest possible time [5].

The routing system of coal emergency logistics vehicles is the mechanism of coal emergency logistics transport services [6]. In the system, the service entities (e.g. supply point and demand point), service objects (e.g. relief items), and service carriers (e.g. road, railway and vehicle) are integrated into an organic whole. The mission of the routing system lies in the timely deployment of relief items in the stricken area through the rational allocation of transport facilities and communication infrastructure [7].

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To fulfil the mission, the routing selection must achieve the minimum time, distance and cost, and maximize the use of the limited vehicle resource. The routing system is the key to smooth rescue operations in the event of coal emergencies. Depending on the coal emergency, the routing problem often requires an urgent solution for multiple, complex targets.

3. Routing problem model

3.1 Multi-target modelling

The way that section titles and other headings are displayed in these instructions, is meant to be followed in the paper.

In the case of a coal emergency, the relief items should be transported and distributed to the stricken area in the shortest possible time. This underscores the importance of the real-time capability of the transport scheduler [8]. Cost-efficiency is another key factor in the routing problem. Hence, the most economical route should be selected to reduce the transport cost and maximize the use of the existing resources.

As a result, the routing problem model must transport the relief items from the distribution centre to the stricken area in the shortest time at the lowest cost, thus enhancing transport efficiency and reducing coal emergency-induced losses.

3.2 Premises

For simplicity, several assumptions are made as follows:

(1) This research only considers the motorable area. The area accessed by helicopters, steamships, etc. is not taken into account.

(2) The distribution centre has enough schedulable vehicles, all of which are of the same type, load capacity and dispatch cost.

(3) The information from the stricken area is fed back in real time. The total demand does not exceed the total load capacity of all vehicles, i.e. no overload is needed.

(4) The loading and unloading processes are not considered.

3.3 Building of multi-target model

3.3.1 Symbol description

$S = \{i|i = 1,2, ..., I\}$ is the set of supply points (distribution centres) of relief items;

$D = \{j|j = 1,2, ..., J\}$ is the set of demand points (help centres) of relief items;

$W = S \cup D$ is the set of stricken areas;

$V = \{l|l = 1,2, ..., L\}$ is the set of transport vehicles;

$G = \{k|k = 1,2, ..., K\}$ is the set of relief items;

Q_L is the maximum load capacity of vehicle l;

q_j is the demand volume of demand point j;

X_{ijl} helps to judge if points i and j are on the route of vehicle l; if yes, X_{ijl} is 1; otherwise, X_{ijl} is 0;

α_{ij} helps to judge if the road is connected; if yes, α_{ij} is 1; otherwise, α_{ij} is 0;

β_{ij} is the congestion rate between points i and j;

d_{ij} is the distance between points i and j;

v_i is the average running speed;

N_1 is the vehicle running cost;

N_2 is the congestion cost;

C_1 is the fixed cost per vehicle;

C_2 is the variable cost per vehicle;

C_3 is the average congestion cost per vehicle.

3.3.2 Quantification of vehicle running cost and congestion cost

The vehicle running cost, a centrepiece of the total transport cost, consists of the fixed cost for starting the vehicle and the variable cost like fuel consumption and vehicle depreciation. Normally, the fixed cost towers over the variable cost. However, the variable cost accounts for the majority of the total transport cost if the vehicle has to cover a long distance or run over damaged road. The vehicle running cost can be expressed as:

$$N_1 = C_1 * L + \sum_{i \in S} \sum_{j \in D} C_2 * d_{ij} * x_{ijl}$$

where C_1*L is the fixed cost for staring the vehicle; $\sum_{i \in S} \sum_{j \in D} C_2 * d_{ij} * x_{ijl}$ is the variable cost.

Under coal emergencies, the road may become bulged, rugged and crowed. The undesirable road conditions are bound to affect the normal running of the vehicle, leading to increased fuel consumption, vehicle depreciation, time delay and rescue difficulty. Considering these factors, the above formula can be revised as:

$$N_2 = \sum_{i \in S} \sum_{j \in D} \alpha_{ij} * \beta_{ij} * d_{ij} * C_3 * x_{ijl}$$

3.3.3 Mathematical model

Objective functions:

$$\min F_1 = \sum_{i \in S} \sum_{j \in D} \frac{d_{ij}}{v_l} \quad ... \quad (1)$$

$$\min F_2 = N_1 + N_2 =$$

$$C_1 * L + \sum_{i \in S} \sum_{j \in D} C_2 * d_{ij} * x_{ijl} +$$

$$\alpha_{ij} * \beta_{ij} * d_{ij} * C_3 * x_{ijl} \quad ... \quad (2)$$

Constraints:

$$\sum_{i \in S} \sum_{j \in D} x_{ijl} q_j \le Q_L, \forall L \in V \quad ... \quad (3)$$

$$\sum_{i \in S} \sum_{j \in D} x_{ijl} = 1, \forall L \in V \quad ... \quad (4)$$

$$\sum_{i \in S} x_{ijl} - \sum_{i \in S} x_{ijl} = 0, \forall j \in D, \forall L \in V \quad ... \quad (5)$$

$$0 \le \beta_{ij} \le 1 \quad \text{... (6)}$$

$$x_{ijl} = \{0,1\}, \forall i, j \in W, \forall L \in V \quad \text{... (7)}$$

$$a_{ij} = \begin{cases} 1 & \text{Points } i, j, \text{ connected} \\ 0 & \text{Points } i, j, \text{ not connected} \end{cases} \quad \text{... (8)}$$

The objective function (1) specifies the minimum time for the vehicle to transport the relief items from the supply points (distribution centres) to the demand points (help centres).

The objective function (2) specifies the minimum cost of transport secluding, including the vehicle running cost (i.e. the sum of the fixed cost and the variable cost), and the congestion cost resulted from poor road conditions.

The constraint (3) means the total demand volume (not exceeding the vehicle's maximum load capacity) of the demand point serviced by the same vehicle on the same road.

The constraint (4) means one demand point is serviced by one vehicle at a time.

The constraint (5) means the vehicle route must be continuous, i.e. the vehicle must enter into and leave from the same point.

The constraint (6) specifies the congestion rate.

The constraint (7) specifies the 0~1 decision variable.

The constraint (8) confirms if the road is connected.

4. GA-based solution to the routing problem model

4.1 Overview of the GA

The GA is a metaheuristic inspired by the process of natural selection. Following the principle of "survival of the fittest", the algorithm finds the optimal solution relying on coding, fitness function, and bio-inspired operators such as mutation, crossover and selection.

Mimicking the genetic evolution, the GA transcends the limits of value, continuity and differentiability. The search process starts from the initial population, rather than a single point, which contributes to the global searching ability. In addition, the GA is time-saving and highly efficient, for the objective function of the optimization model is transformed into the fitness function, such that the search always goes in the right direction and range.

4.2 GA-based solution

4.2.1 Building of genetic coding and initial scheduling plan

The symbolic coding was adopted with supply points (distribution centres) denoted as 0, and demand points (help centres) as 1, 2, 3,…, n. For example, chromosome: 0 2 3 0 5 4 0 6 7 8 0 9 10 1 means there are 4 vehicles transporting relief items to 10 distribution centres via the following routes:

Route 1: Supply point 0 → Demand point 2 → Demand point 3

Route 2: Supply point 0 → Demand point 5 → Demand point 4

Route 3: Supply point 0 → Demand point 6 → Demand point 7 → Demand point 8

Route 4: Supply point 0 → Demand point 9 → Demand point 10 → Demand point 1

The points in each route must follow the pre-set sequence, but not the routes themselves. Hence, the routes can be reordered without changing the value of the objective functions.

4.2.2 Fitness function

The following fitness-function transfer approach is adopted for this research [9]:

$$Fit(f(x)) = c/f(x),\ f(x) > c \quad \text{... (9)}$$

where c is the minimum value of each objective function. The value of c ensures that the fitness function value falls in the range of (0,1), making it easy to control [10][11].

Then, the weight coefficient was introduced to solve the multi-target optimization problem [12]. The weight coefficients of the two objective functions are denoted as μ_1 and μ_2 respectively. Plus, $0<\mu_1$, $\mu_2<1$, $\mu_1>\mu_2$ and $\mu_1+\mu_2 = 1$. The weight coefficients were configured in light of references [13].

Then, the comprehensive fitness of the chromosome (l) (i.e. the l-th chromosome in the initial population) can be expressed as:

$$F(l) = \mu_1 \frac{F_{1\min}}{F_1(l)} + \mu_2 \frac{F_{2\min}}{F_2(l)} \quad \text{... (10)}$$

where F_1 (l) and F_2 (l) are the two objective function values of chromosome (l); $F_{1\min}$ and $F_{2\min}$ are the minimum values obtained through 15 tests.[14]

4.2.3 Genetic manipulation

The popular roulette method of the classic GA was employed to perform the selection operation. For effective scheduling, the common 2-point crossover approach was improved in light of the actual conditions. The operation steps are detailed below:

(1) When the front and back genes in the crossover part are zero, exchange the part between the two points of the two chromosomes, compare the copied gene with the reserved gene in the prochromosome, delete the duplicate genes and fill in with the unnecessary demand point(s).

(2) When the front and back genes in the crossover part are non-zero, move the crossover point until the front and back genes in the crossover part are zero, and repeat the operations in Step (1).

The basic bit mutation was used to exchange any two genes on two chromosomes, forming a new transport route at random.

4.3 Case study

The above GA-based mathematical model was applied to the following example to verify their feasibility and effectiveness.

Example: There are 1 distribution centre, 4 vehicles and 20 help centres; the centre coordination, demand volume, vehicle information, distance matrix (between the distribution centre and help centres) and congestion situation are all randomly generated.

The aim is to set a reasonable transport route so that the vehicles could deliver the relief items in the shortest time at the lowest cost.

Here, it is assumed that the vehicle load capacity Q = 30t, the average running speed v = 50km/h, the fixed cost C_1 = RMBY 100 per time, the variable cost C_2 = RMBY 30 per time, and the congestion cost C_3 = RMBY 20 per km.

The GA parameters are set as: the population size N = 200, the crossover probability p_c = 0.7, the mutation probability p_m = 0.05, and the maximum number of iteration = 1,000. The weights of objective functions are F_1 = 0.8 and F_2 = 0.2.

4.3.1 Inputs

The information of the distribution centre and the help centres were inputted systematically, including the centre coordinates, weight of relief items, vehicle information, distance matrix and congestion rate. The inputs are listed in Tables 1~5, respectively.

TABLE 1: INFORMATION ON COAL EMERGENCY-RESCUE VEHICLE

	Max. weight (t)	Fixed cost (RMBY)	Variable cost (RMBY)	Average speed (km/h)
1	30	100	30	50
2	30	100	30	50
3	30	100	30	50
4	30	100	30	50

TABLE 2: DISTRIBUTION CENTER COORDINATES

Distribution enter no.	Coordinate X (km)	Coordinate Y (km)
1	8.1472	0.3571

4.3.2 Outputs

The experiment was run on Matlab R2011b and a laptop (Intel Core 2 Duo 1.83G; 2G memory), using the above GA-based mathematical model. Figs.1 and 2 respectively show the optimal solution and the evolution process obtained by the two objective functions, with the aim of achieving the shortest delivery time at the lowest cost. During the experiment, the solution started to converge to a certain value at a certain cycle of iteration, indicating that our algorithm has a good convergence performance.

minObjv 1 = 1.0419

minObjv 2 = 2.1714e + 003

Fitness = 0.9571

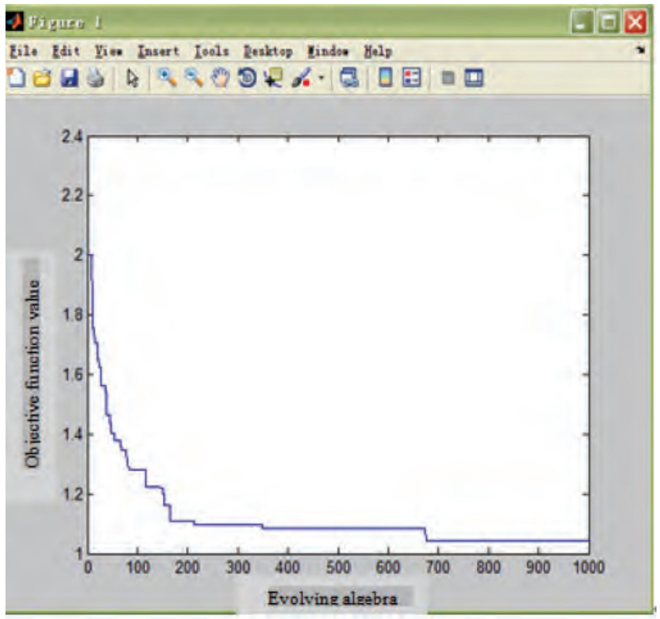


Fig.1 Convergence of objective function F_1

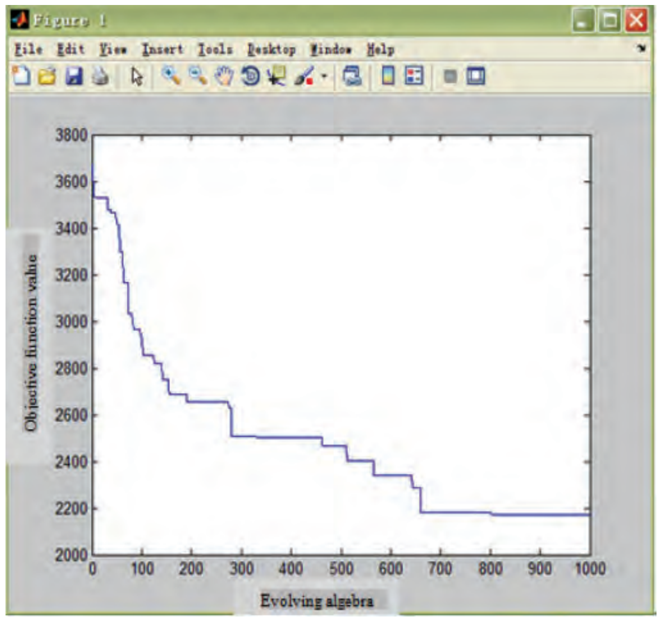


Fig.2 Convergence of objective function F_2

The above data means the optimal values of the two objective functions are F_1 = 1.0091 and F_2 = 2176.3, respectively, and the comprehensive fitness is 0.957.

The final scheduling plan is shown in Fig.3 below.

As per the optimal routing plan, the four vehicles should each follow the routes below:

Vehicle 1: 0 → 15 → 11 → 7 → 6 → 20 → 16 → 3

Vehicle 2: 0 → 1 → 9 → 2 → 4

Vehicle 3: 0 → 19 → 10 → 13 → 17

Vehicle 4: 0 → 12 → 18 → 8 → 5 → 14

Table 3: Distance matrix between distribution centerand help point

	0	1	2	3	4	5	6	7	8	9
0	0	8.184996412	11.31323022	6.505470326	7.44702541	10.07370852	6.439261917	6.751663377	1.9682608	6.869481074
1	8.184996412	0	7.834151548	1.705628404	2.883009153	8.151722939	7.760522587	4.078204983	6.799122179	1.548070255
2	11.31323022	7.834151548	0	8.26779545	5.352256106	1.931189487	5.625534207	5.038674091	11.2766899	8.683543045
3	6.505470326	1.705628404	8.26779545	0	2.91911153	8.183730795	6.965317839	3.672315337	5.094634332	0.58304744
4	7.44702541	2.883009153	5.352256106	2.91911153	0	5.350182957	5.08741055	1.332816853	6.706458797	3.365234049
5	10.07370852	8.151722939	1.931189487	8.183730795	5.350182957	0	3.948168743	4.578108364	10.32794383	8.681406445
6	6.439261917	7.760522587	5.625534207	6.965317839	5.08741055	3.948168743	0	3.759396451	7.140808985	7.547278146
7	6.751663377	4.078204983	5.038674091	3.672315337	1.332816853	4.578108364	3.759396451	0	6.349418233	4.210546378
8	1.9682608	6.799122179	11.2766899	5.094634332	6.706458797	10.32794383	7.140808985	6.349418233	0	5.349103359
9	6.869481074	1.548070255	8.683543045	0.58304744	3.365234049	8.681406445	7.547278146	4.210546378	5.349103359	0
10	6.571220527	11.08036598	9.026800972	9.948165499	8.673668809	7.138318278	3.801278422	7.351619258	8.119418147	10.51787599
11	2.871899532	5.758638929	10.69304613	4.058654906	5.878665257	9.897331634	7.016337395	5.681857533	1.065429797	4.291610141
12	1.428267777	8.045997797	12.15494427	6.340777362	7.821957012	11.06667311	7.618042679	7.345669089	1.250157592	6.599198733
13	3.350262063	8.61539397	9.103733681	7.221126379	6.767625648	7.534806326	3.603879447	5.617235525	4.77903742	7.750543473
14	7.878785458	1.085895698	6.823066917	1.836714971	1.803229126	7.073158848	6.769170753	3.040202087	6.709528829	2.021913259
15	9.418838798	7.793333459	2.39628282	7.716573562	4.944911838	0.655730378	3.320098436	4.069024164	9.692459291	8.230786397
16	4.833203344	7.192644924	6.837030837	6.10299312	4.883806765	5.35372099	1.61766661	3.607700404	5.552601555	6.680319426
17	9.200720672	1.015805967	7.889156481	2.714971485	3.425659124	8.439960599	8.470123006	4.721518789	7.801544309	2.49074122
18	0.225518971	8.225632017	11.1879553	6.555838796	7.407467129	9.923701588	6.260225641	6.677314294	2.145272018	6.93444568
19	4.282444747	4.13883494	9.686779919	2.443815047	4.569183947	9.141189243	6.825811114	4.660699346	2.675650394	2.673561893
20	3.806383907	5.30234024	7.646992001	3.933063231	3.769076065	6.650739311	3.773933057	2.947578275	3.678574212	4.481792132

	10	11	12	13	14	15	16	17	17	19	20
1	11.08036598	5.758638929	8.045997797	8.61539397	1.085895698	7.793333459	7.192644924	1.015805967	8.225632017	4.13883494	5.30234024
2	9.026800972	10.69304613	12.15494427	9.103733681	6.823066917	2.39628282	6.837030837	7.889156481	11.1879553	9.686779919	7.646992001
3	9.948165499	4.058654906	6.340777362	7.221126379	1.836714971	7.716573562	6.10299312	2.714971485	6.555838796	2.443815047	3.933063231
4	8.673668809	5.878665257	7.821957012	6.767625648	1.803229126	4.944911838	4.883806765	3.425659124	7.407467129	4.569183947	3.769076065
5	7.138318278	9.897331634	11.06667311	7.534806326	7.073158848	0.655730378	5.35372099	8.439960599	9.923701588	9.141189243	6.650739311
6	3.801278422	7.016337395	7.618042679	3.603879447	6.769170753	3.320098436	1.61766661	8.470123006	6.260225641	6.825811114	3.773933057
7	7.351619258	5.681857533	7.345669089	5.617235525	3.040202087	4.069024164	3.607700404	4.721518789	6.677314294	4.660699346	2.947578275
8	8.119418147	1.065429797	1.250157592	4.77903742	6.709528829	9.692459291	5.552601555	7.801544309	2.145272018	2.675650394	3.678574212
9	10.51787599	4.291610141	6.599198733	7.750543473	2.021913259	8.230786397	6.680319426	2.49074122	6.93444568	2.673561893	4.481792132
10	0	8.491202322	7.996824241	3.342039067	10.19652628	6.631822753	3.887818467	11.90877142	6.345996285	8.992149149	6.086371054
11	8.491202322	0	2.311418424	5.174558369	5.724566524	9.281160979	5.503000683	6.755301237	3.010256115	1.622016498	3.317836885
12	7.996824241	2.311418424	0	4.745355537	7.929612687	10.41843883	6.000510448	9.049995334	1.653758105	3.925798567	4.509348822
13	3.342039067	5.174558369	4.745355537	0	7.916530632	6.893666809	2.289816065	9.554960115	3.131695666	5.843679257	3.315460516
14	10.19652628	5.724566524	7.929612687	7.916530632	0	6.708414889	6.321989807	1.714614756	7.890530488	4.163566985	4.649374144
15	6.631822753	9.281160979	10.41843883	6.893666809	6.708414889	0	4.701162512	8.149038996	9.268346636	8.567723529	6.01817664
16	3.887818467	5.503000683	6.000510448	2.289816065	6.321989807	4.701162512	0	8.030284798	4.659648248	5.513186553	2.42695956
17	11.90877142	6.755301237	9.049995334	9.554960115	1.714614756	8.149038996	8.030284798	0	9.240697156	5.133459778	6.252804092
18	6.345996285	3.010256115	1.653758105	3.131695666	7.890530488	9.268346636	4.659648248	9.240697156	0	4.37540172	3.729747219
19	8.992149149	1.622016498	3.925798567	5.843679257	4.163566985	8.567723529	5.513186553	5.133459778	4.37540172	0	3.090879151
20	6.086371054	3.317836885	4.509348822	3.315460516	4.649374144	6.01817664	2.42695956	6.252804092	3.729747219	3.090879151	0

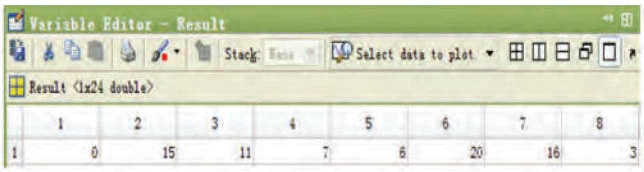
Table 4: Road blocking rate

	0	1	2	3	4	5	6	7	8	9
0	0	0.549723608	0.165648729	0.868694705	0.239916154	0.95613454	0.780227435	0.587044705	0.594896074	0.546805719
1	0.549723608	0	0.601981941	0.084435846	0.123318935	0.575208595	0.081125769	0.207742293	0.262211748	0.521135831
2	0.165648729	0.601981941	0	0.399782649	0.183907788	0.059779543	0.929385971	0.30124633	0.602843089	0.231594387
3	0.868694705	0.084435846	0.399782649	0	0.239952526	0.234779913	0.775712679	0.470923349	0.71121578	0.488897744
4	0.239916154	0.123318935	0.183907788	0.239952526	0	0.353158571	0.486791632	0.23048816	0.221746734	0.624060088
5	0.95613454	0.575208595	0.059779543	0.234779913	0.353158571	0	0.435858589	0.844308793	0.117417651	0.679135541
6	0.780227435	0.081125769	0.929385971	0.775712679	0.486791632	0.435858589	0	0.19476429	0.296675873	0.395515216
7	0.587044705	0.207742293	0.30124633	0.470923349	0.23048816	0.844308793	0.19476429	0	0.318778302	0.367436649
8	0.594896074	0.262211748	0.602843089	0.71121578	0.221746734	0.117417651	0.296675873	0.318778302	0	0.987982003
9	0.546805719	0.521135831	0.231594387	0.488897744	0.624060088	0.679135541	0.395515216	0.367436649	0.987982003	0
10	0.494173937	0.779051723	0.715037078	0.903720561	0.890922504	0.334163053	0.698745832	0.197809827	0.030540946	0.74407426
11	0.028674152	0.489901389	0.167927146	0.97868065	0.712694472	0.500471624	0.471088375	0.059618868	0.681971904	0.042431138
12	0.800330575	0.453797709	0.432391504	0.825313795	0.083469815	0.133171008	0.173388613	0.390937802	0.831379743	0.803364392
13	0.106216345	0.37240974	0.198118403	0.489687638	0.339493413	0.951630465	0.92033204	0.052676998	0.737858096	0.269119426
14	0.178132454	0.1280144	0.999080395	0.171121066	0.032600821	0.561199793	0.8818665	0.669175305	0.190433267	0.368916546
15	0.22618768	0.384619124	0.582986383	0.251806122	0.290440664	0.617090884	0.26528091	0.824376267	0.9826634	0.730248792
16	0.161484744	0.178766187	0.422885689	0.094229339	0.598523669	0.470924256	0.695949313	0.69988785	0.638530758	0.033603836
17	0.610958659	0.778802242	0.423452919	0.090823286	0.266471491	0.153656718	0.281005303	0.440085139	0.527142742	0.457424366
18	0.254790157	0.224040031	0.667832727	0.844392157	0.344462411	0.780519653	0.675332066	0.006715314	0.602170488	0.386771195
19	0.721758033	0.473485993	0.1527212	0.341124607	0.607389214	0.191745255	0.73842684	0.242849598	0.917424342	0.269061587
20	0.635786711	0.945174113	0.208934922	0.709281703	0.236230577	0.119396248	0.607303941	0.450137697	0.458725494	0.661944752

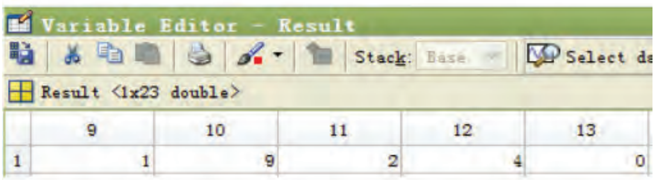
	10	11	12	13	14	15	16	17	18	19	20
0	0.494173937	0.028674152	0.800330575	0.106216345	0.178132454	0.22618768	0.161484744	0.610958659	0.254790157	0.721758033	0.635786711
1	0.779051723	0.489901389	0.453797709	0.37240974	0.1280144	0.384619124	0.178766187	0.778802242	0.224040031	0.473485993	0.945174113
2	0.715037078	0.167927146	0.432391504	0.198118403	0.999080395	0.582986383	0.422885689	0.423452919	0.667832727	0.1527212	0.208934922
3	0.903720561	0.97868065	0.825313795	0.489687638	0.171121066	0.251806122	0.094229339	0.090823286	0.844392157	0.341124607	0.709281703
4	0.890922504	0.712694472	0.083469815	0.339493413	0.032600821	0.290440664	0.598523669	0.266471491	0.344462411	0.607389214	0.236230577
5	0.334163053	0.500471624	0.133171008	0.951630465	0.561199793	0.617090884	0.470924256	0.153656718	0.780519653	0.191745255	0.119396248
6	0.698745832	0.471088375	0.173388613	0.92033204	0.8818665	0.26528091	0.695949313	0.281005303	0.675332066	0.73842684	0.607303941
7	0.197809827	0.059618868	0.390937802	0.052676998	0.669175305	0.824376267	0.69988785	0.440085139	0.006715314	0.242849598	0.450137697
8	0.030540946	0.681971904	0.831379743	0.737858096	0.190433267	0.9826634	0.638530758	0.527142742	0.602170488	0.917424342	0.458725494
9	0.74407426	0.042431138	0.803364392	0.269119426	0.368916546	0.730248792	0.033603836	0.457424366	0.386771195	0.269061587	0.661944752
10	0	0.071445465	0.060471179	0.422835615	0.460725937	0.343877004	0.068806099	0.875371599	0.915991244	0.765500017	0.770285515
11	0.071445465	0	0.399257771	0.547870901	0.981637951	0.584069333	0.319599735	0.518052108	0.001151057	0.188661977	0.350218013
12	0.060471179	0.399257771	0	0.942736984	0.156404952	0.107769015	0.530864281	0.943622625	0.462449159	0.287498173	0.662009598
13	0.422835615	0.547870901	0.942736984	0	0.855522806	0.906308151	0.654445708	0.637709098	0.42434904	0.091113464	0.41615859
14	0.460725937	0.981637951	0.156404952	0.855522806	0	0.879653724	0.407619197	0.95769394	0.460916366	0.576209381	0.841929153
15	0.343877004	0.584069333	0.107769015	0.906308151	0.879653724	0	0.819981223	0.240707035	0.770159729	0.683363243	0.832916819
16	0.068806099	0.319599735	0.530864281	0.654445708	0.407619197	0.819981223	0	0.676122304	0.322471807	0.546593115	0.256440992
17	0.875371599	0.518052108	0.943622625	0.637709098	0.95769394	0.240707035	0.676122304	0	0.784739295	0.425728842	0.613460737
18	0.915991244	0.001151057	0.462449159	0.42434904	0.460916366	0.770159729	0.322471807	0.784739295	0	0.644442781	0.582249165
19	0.765500017	0.188661977	0.287498173	0.091113464	0.576209381	0.683363243	0.546593115	0.425728842	0.644442781	0	0.540739337
20	0.770285515	0.350218013	0.662009598	0.41615859	0.841929153	0.832916819	0.256440992	0.613460737	0.582249165	0.540739337	0

Table 5: Coordinate of help point and weight of needed relief items

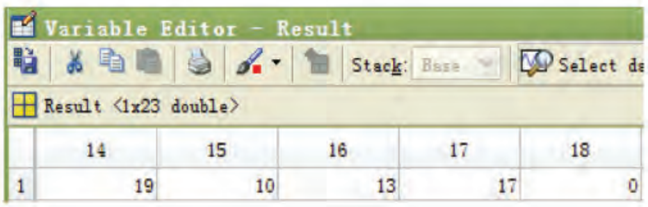
Help point no.	Coordinate X (km)	Coordinate Y (km)	Weight of needed relief items (t)
1	9.0579	8.4913	1.8000
2	1.2699	9.3399	2.4000
3	9.1338	6.7874	1.2000
4	6.3236	7.5774	6
5	0.9754	7.4313	4.2000
6	2.7850	3.9223	3
7	5.4688	6.5548	4.2000
8	9.5751	1.7119	3.6000
9	9.6489	7.0605	4.2000
10	1.5761	0.3183	3.6000
11	9.7059	2.7692	4.8000
12	9.5717	0.4617	3.6000
13	4.8538	0.9713	6
14	8.0028	8.2346	1.8000
15	1.4189	6.9483	1.2000
16	4.2176	3.1710	1.2000
17	9.1574	9.5022	0.6000
18	7.9221	0.3445	3
19	9.5949	4.3874	3
20	6.5574	3.8156	2.4000



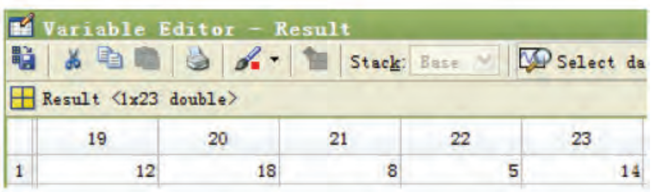
(a) Optimal routing plan field (1-8)



(b) Optimal routing plan field (9-13)



(c) Optimal routing plan field (14-18)



(d) Optimal routing plan field (19-23)

Fig.3 Optimal routing plan

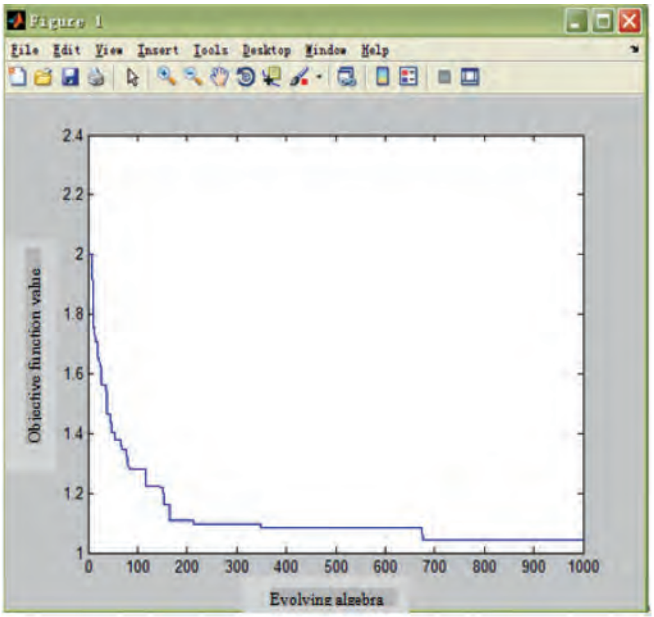


Fig.4 Performance chart of F_1 our algorithm

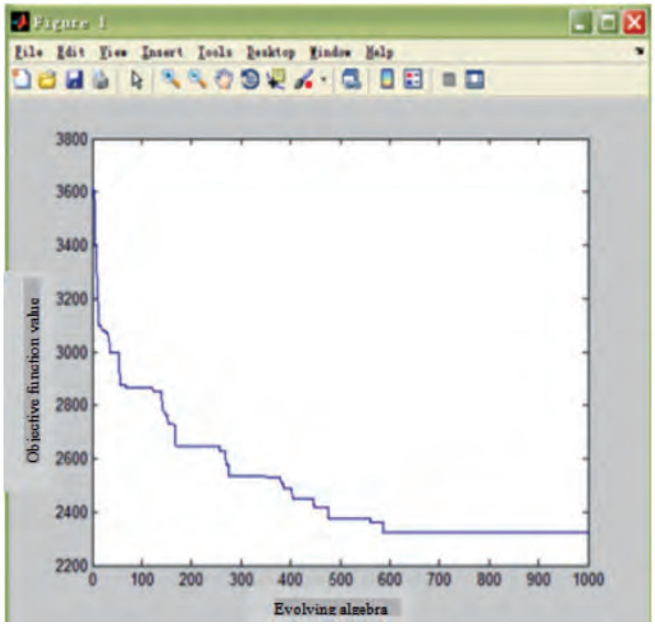


Fig.5 Performance chart of F_2 our algorithm

Next, the results recorded in the experiment were compared one by one. After the experimental programme ran 15 times, the recorded values of objective function F_1 were respectively 2.196, 1.307, 2.192, 1.041, 1.276, 1.009, 1.171, 1.336, 1.251, 1.103, 1.099, 2.216, 1.676, 1.407 and 1.175, putting the mean value at 1.35 and the standard deviation at 0.55; those of objective function F_2 were respectively 2,196.5, 2,307.3, 2,192.8, 2,403.6, 2,276.8, 2,209.8, 2,171.4, 2,336, 2,251.2, 2,303.1, 2,199.4, 2,216.6, 2,176.3, 2,407.3 and 2,175.5, putting the mean value at 2,254.91 and the standard deviation at 77.99. The results show that the results are generally stable, an indicator of the rationality of our algorithm.

4.3.3 Rationality test of the maximum number of iterations and the control parameters

(1) Rationality test of the maximum number of iterations

In the 15 experiments, the maximum number of iterations was set to 1,000. As shown in the Figs.4 and 5, the objective function values gradually stabilized (i.e. the values were not likely to change) between 450~650 generations, and never changed after the 700th generation. Therefore, the pre-set maximum number of iterations allows the population to evolve to the optimal state in a limited amount of time.

(2) Rationality test of the control parameters

First, the crossover probability was increased from 0.7 to 0.9, while the mutation probability remained at 0.05. According to the results of ten experiments, the final values of the objective functions fluctuated violently with the increase in crossover probability; the solution time increased by 11.21% and 41.57%, respectively, while the optimal solution value was generally low.

The standard deviation reflects the dispersion degree of the experimental results. For a rational test method, the results should stay closely to the true value; otherwise, the results may be far away from the true value. Since it increased from 0.7 to 0.9, the crossover probability undermines the population evolution, extends the number of iterations, and randomizes the search results. Thus, it fails to achieve a fine effect in solving our problem.

Second, the crossover probability was decreased from 0.7 to 0.5, while the mutation probability remained at 0.05. According to the results of ten experiments, as the crossover probability fell from 0.7 to 0.5, the solution time was shortened by 23.42% and 21.22% respectively. However, the objective functions fluctuated even more violently, the optimal solution value was still generally low, and the standard deviation was greater than ever. This means the adjustment failed to improve the algorithmic efficiency.

There is not uniform standard for selecting the mutation probability. The parameter should be set and adjusted according to the actual conditions. According to the results of ten experiments, the relationship between the selected mutation probability and the optimal solution is as follows:

First, the mutation probability was increased from 0.05 to 0.08, while the crossover probability remained at 0.7. According to the results of ten experiments, as the mutation probability grew from 0.05 to 0.08, the mean value exhibited a decreasing trend, the mean deviation increased by 6.23%, and the standard deviation rose by 2.65%. The increased mutation probability undermines the population evolution, and cannot enhance the algorithm performance.

Second, the mutation probability was decreased from 0.05 to 0.02, while the crossover probability remained at 0.7. According to the results of ten experiments, as the mutation probability fell from 0.05 to 0.02, the solution time was shortened by 3.03% and 10.51%, respectively. However, the values of the objective functions were generally low, with an even greater standard deviation. These results reveal that the algorithm will not be more efficiency through the adjustment of the crossover probability and the mutation probability.

Through the above analysis on the maximum number of iterations and control parameters, it is concluded that the max.gen = 1000, $p_c = 0.7$ and $p_m = 0.05$ are reasonable. The pre-set values can stabilize the result, shorten the solution time, and effectively solve the example problem.

5. Conclusions

Based on some rational assumptions, this paper builds a mathematical model to select effective routes for coal emergency logistics vehicles, aiming to shorten the transport time and cost as much as possible. The GA was introduced to enhance the model with coding method, fitness functions and genetic operators. Through an example analysis, it is concluded that our algorithm converges well in the solution to the routing problem. This research provides strong supports to coal emergency management agencies in transport route design, allocation of relief items, manpower and vehicles, and reduction of coal disaster loss.

Of course, this research also has its downsides. During the analysis, the fitness function was transformed into the weighted function in reference to [7][8][9]. The distribution of weight coefficient mainly aims to highlight the important difference between the two functions. However, there is still a lack of strict quantitative analysis. Moreover, the search efficiency should be further improved, although the selection, crossover and mutation were configured rationally to ensure solution quality. These limitations will be tackled in the future research.

Acknowledgment

This research has been supported in part by the Jiangxi Province Electronic Commerce high level Engineering Research Center, China. Additionally, supported by Yiwu Industrial and Commercial College, and also supported by Research on Adoption and Sustained Use of Mobile Social Network Users (71261008, National Natural Science Foundation of China), Research on the Influence of Mobile Social Network on Network Public Opinion and Its Governance (14CTQ031, National Social Science Foundation of China), Exploring the Construction of Entrepreneurship College Based on Mixed Ownership Model (Taking Yiwu Institute of Business and Technology as an Example) (jg20160349, Zhejiang Province Higher Education Teaching

Reform Project), and An Empirical Study on the Mining and Sharing of Tacit Knowledge in Higher Vocational Education (Y201432371, Zhejiang Provincial Department of Education).

The authors are indebted to Zhongjian Le, Xiaohong Gan, Juling Dingfor their assistance on earlier drafts, and I also would like to thank many colleagues for their constructive criticism and helpful suggestions for improving the overall quality of this paper.

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