Supplies transportation planning in power grid urgent repair based on hierarchical genetic algorithm

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Abstract

To optimize supplies transportation solutions of power grid, a hierarchical genetic algorithm is put forward. Double hierarchical objective function is set by weighting, that is, when the precondition of inequality constraint is met, objective solution is to find out the shortest supply time and if the solution is also within the time constraint, the final solution would be the least supply cost, otherwise, it would still be the shortest supply time. The solution for optimal supplies transportation scheme at the least cost would be worked out by iteration of genetic algorithm. Compared with single objective genetic algorithm in simulation, hierarchical genetic algorithm is proved more effective and superior to decrease economic loss of accidents.

Keywords: Hierarchical Genetic Algorithm, Time constraint, Transportation Cost, Transportation Time, Economic Loss

1 Introduction

After a power grid accident, the first important thing is to quickly make emergency supplies allocated to the destination, thus to decrease economic loss. Whenever a great disaster occurs, one supply warehouse could often hardly meet the demand for emergency supplies so that to cause the problem of multi-site to rescue. In Literatures [1, 2], the problem of supplies scheduling within the shortest time from the least supplies sites are discussed in terms of strictly mathematical proof. In Literatures [3, 4, 5], the optimal path multi-material in electric power scheduling is worked out by Dijkstra algorithm and an overall optimization on planning is realized by establishing an independent scheduling system. In Literature [6], emergency supply scheduling at single accident site is studied by taking the least supply sites and the shortest emergency responding time as the objective functions. In Literature [7], under the condition of time constraint at single supply site and multiple accident sites, the scheduling problem of single type supplies is discussed, and a model for emergency supply scheduling is proposed to aim at the shortest responding time.

So far, researches on urgent repair mostly focus on solutions for optimal path. However, this paper tries to find out a solution to decrease economic loss by analysing the problems of multi- sites of supply & demand, and scheduling. Taking the minimal economic loss as the objective, optimal planning in power grid emergency repair is elicited by iteration of genetic algorithm based on a double-hierarchical model of the shortest transportation time and minimal transportation cost.

2 Modelling

To simplify model, assumptions are made below.

a) Impacts by traffic jams, traffic light and so on would be ignored, that is, the consumed time is a constant from a supply site to a demand site.

b) Quantities for different demanded supplies are integers, that is, there are no requirements to combine specific quantity and special type supplies at fault sites.

c) There is no restriction on vehicles at each supply site, that is, arbitrary transportation at a supply site is allowed.

Assumed that there are m power grid supply sites and $P=\{P_1,P_2,..P_m\}$, where there are l kinds of supplies and $S=\{S_1,S_2,..S_l\}$, supplies would be distributed to n fault sites and there is $Q=\{Q_1,Q_2,..Q_n\}$. Given that the demand amount for supplies k at the i-th supply site is A_{ki}, where there are $k\in(1,l)$ and $i\in(1,m)$, while the demand amount for supplies k at the j-th supply site is B_{kj}, where there are $k\in(1,l)$ and $j\in(1,n)$. Assumed that

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the consumed time from the supply site i to the fault site j is t_{ij}, where there are $i \in (1,m)$ and $j \in (1,n)$. c_{ij} is the unit cost by transport supplies from supply site P_i to Q_j. The purpose of supplies transportation planning in urgent repair is to determine the supply amount from each supply site to the demand site, i.e., to find the solver of x_{ijk}, which is the amount of supplies S_k transported from supply site P_i to demand site Q_j. D_{ijk} represents the activity of supplies transportation from supply site P_i to demand site Q_j, when x_{ijk} is more than 0, there is $D_{ijk} = 1$, otherwise there is $D_{ijk} = 0$. For an arbitrary k, if there is $D_{ijk} = 1$, there is $D_{ij} = 1$, that is, the supplies transportation from supply site i to demand site j occur, where there are $i \in (1,m)$, $j \in (1,n)$, and $k \in (1,l)$.

According to assumptions and descriptions above, the model would be established as below.

$$\min\left\{\lambda_1 \times \max\left(D_{ij}t_{ij}\right) + \lambda_2 \sum c_{ij}x_{ij}\right\} \tag{1}$$

There are three inequality constraints below.

$$\forall k, \sum_i A_{ki} \geq \sum_j B_{kj} \tag{2}$$

$$\forall j, \forall k, \sum_i x_{ijk} \geq B_{kj} \tag{3}$$

$$\forall i, \forall k, \sum_i x_{ijk} \geq A_{kj} \tag{4}$$

In formula (1), when the real transportation time is less than the critical time t_m, there are $\lambda_1 = 0$ and $\lambda_2 = 1$; on the contrary, then λ_1 and λ_2 would be calculated by normalization of weights from practical data. Besides, $D_{ij}t_{ij}$ represents the consumed time from site i to site j in this algorithm. Formula (2) shows that the total amount of supplies S_k from all supply sites could meet the demand at fault site. Formula (3) shows that the amount of supplies S_k sent to fault site Q_j has actually met the demand. Formula (4) shows that the amount of supplies S_k from supply site P_i is less than its reserve [8].

3 A double hierarchical planning on supplies transportation

After a power grid accident, the most important thing for material transportation is to quickly make emergency supplies allocated to the destination, thus to lower economic loss to minimum. In practice, t_{kij}, the consumed time from resource site to demand site, is always assumed to be a constant, then the time taken to handle the power grid fault is $T_s = \max\{t_{kij}\} + t_k$, where t_k is the time to repair. Therefore, when there is $T_s \in (0, T_{\min})$, there is $L(t) = 0$, where $L(t)$ is the function of economic loss to time, and when there is $T_s \in (T_{\min}, T_{\max})$, there is $L(t) = k(T_{\max} - T_{\min})$ with a linear relationship. When T_s is longer than $T_{\max}$, the most severe economic loss $L_{\max}$ would be there. Usually, the needed time to repair would be taken as the critical time T_r to judge if economic loss has been caused or not since once supplies are sent to demand site, the needed time to repair T_k is only related to the skills of rescue team without obvious variation. However, the supplies transportation time T_m would change with the road actual situation and the supplies scheduling & planning, so to tremendously influence T_r.

The objective of single hierarchical algorithm is to directly calculate the shortest path or the consumed time based on the shortest path. However, not only an analysis of the shortest path but also a quantitative analysis, where if the consumed time meets the requirement of shortest time at minimal economic loss, should be done in practice. Under this condition, when there is a solution for the shortest path, the objectives would change into the minimal transportation cost and minimal number of rescue; when there is no a solution, the objective would be the shortest transportation time due to the trivial distribution cost comparing with the economic loss by fault itself [9].

Therefore, double hierarchical indicators should be established, on the upper hierarchy are economy-effectiveness-type indicators to ensure supplies transportation within the shortest time; on the lower hierarchy are cost-type indicators which will realize the minimum of objective function only after meeting the condition of the shortest transportation time on the upper hierarchy as shown in formula (1). In practice, great amount of supplies always are badly needed at the spot of fault site within a short time so that those distant and time-consuming transportations are necessary but undesirable while considering the limitation of time. When the time constraint is not met, c_{ij} of transportation cost for this route would be substituted with a figure much bigger than it is possible in practice, other transportation costs for other route would not change [10]. That is, supplies transportation planning would change under different time constraint.

4 Hierarchical Planning Based on Genetic Algorithm

Supply sites would be different with the different limitation on transportation time at fault sites. When the premise of time constraint is met, the optimal and minimal solution of objective function could be worked out by data comparison.

4.1 CODING

Since the purpose of supplies planning is to find out the optimal transportation plan, codes could be expressed as $(x_{111}, x_{112}, \ldots, x_{121} x_{122}, \ldots, x_{211} x_{212}, \ldots, x_{mnl})$, where x_{mnl} represents the amount of supplies l from supply site m to demand site n, P is the set of supply sites, and Q is the set of demand sites.

4.2 INITIAL POPULATION'S ESTABLISHMENT

$tempx_{ijk}$ represents the amount of supplies k from the practical supply site i to fault site j and $tempA_{ik}$ is the left one of supplies k at site i. According to statistical data, there is a limitation on the optimal shortest time, within which the rescue could be implemented at a minimal loss or beyond which the loss would raise with the increase of the consumed time. Given that the optimal shortest time is t_m, there would be two situations: The first one is that supplies in reserve could meet the demand at fault site for each supply sites where there is $t_{ij} \le t_m$; The second one is that supplies only at those supply sites where there is $t_{ij} > t_m$ could meet the demand at fault site. The process is described step by step and shown in Figure 1.

Step 1: To judge if $\sum_i x_{ijk} \ge B_{kj}$ is false at fault site j, or the process goes to Step 5.

Step 2: For specific fault site j, the set E of supply sites, where $t_{ij} \le t_m$ is true, would be established, then to judge if $temp\sum_i \sum_k x_{ijk} < \sum_j B_{kj}$ is true, where $temp\sum_i \sum_k x_{ijk}$ represents the total amount of supplies k at fault site j, or the process goes to Step 4.

Step 3: For the above site j, supply site r, where there is $t_{rj} > t_m$, would be push into the serial R. Then those t_{rj} while $r \in R$ are sorted in ascending order that the maximal amount of supplies as $x_{rjk} = A_{rk}$ would be added to the total amount of supplies as $B'_{kj} = B'_{kj} + A_{rk}$ until there $B'_{kj} = \sum_i x_{ijk} \ge B_{kj}$ is true. Finally, t_{ij} would be assigned to t_m.

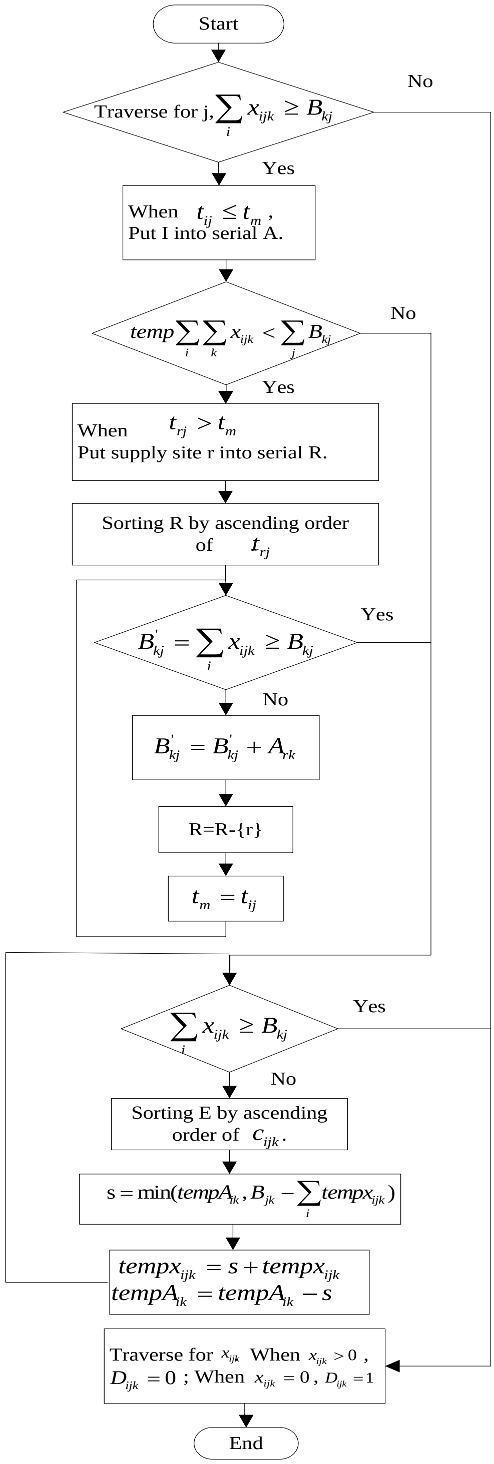

FIGURE 1 Flow chart of double hierarchical genetic algorithm model

Step 4: To judge if $\sum_i x_{ijk} \ge B_{kj}$ is true, as for supplies k, the set E would be sorted according to the ascending order of c_{ijk}, the amount s of supplies from i to j is $s = \min\left(tempA_{ik}, B_{jk} - \sum_i tempx_{ijk}\right)$ according to the ascending order, where $\sum_i x_{ijk}$ are those values, which meet conditions in above steps. If there are $tempx_{ijk} = s + tempx_{ijk}$ and $tempA_{ik} = tempA_{ik} - s$, the process will redo step 4.

Step 5: As for site j, when x_{ijk} is true, there it is $D_{ijk} = 1$ at site i, or there it is $D_{ijk} = 0$ and the process goes to the end.

4.3 FITNESS FUNCTION

Since the objective function is designed as the minimum, the fitness function would be designed as $F(x) = 1\frac{1}{f(x)}$, where $f(x)$ is the minimal objective function.

4.4 SELECTION, CROSSOVER AND MUTATION

Selection operator would be conducted by means of wheel selection. The locations of supply sites and fault site are fixed for initial codes, thus crossover operator would be conducted in terms of crossover from a supply site to another one. To show the general features of the algorithm, the probabilities of crossover and mutation are expressed with random number as $P_c = random(0.5,1)$ and $P_r = random(0.01,0.1)$ respectively. To meet the limiting conditions above and to avoid infeasible solutions, the process is described below.

Step 1. According to the result of random number, chromosome could be selected to pair. If the pairing result is $random[0,1] < P_c$, where P_c is the probability of crossover, pairing by crossover operation would be conducted, or mutation operation would be done.

Step 2. In terms of stochastic method, the random number of w within the interval of $[1,l]$ would be got and then the crossover transform on the practical amount of supplies w would be conducted.

Step3. An entity is randomly selected from the population, and judgment that if $random[0,1] < P_r$ is true or not would be made, where P_r is the mutation probability. When the condition is met, mutation operation would be conducted: Firstly, the practical amount of transported supplies to demand site j is set as 0. Then, the supplies planning would be reset for demand site j according to the process of population initialization.

5 Case Studies

In this paper, the genetic algorithm tool kit of Matlab is applied. For a same case of emergency scheduling, simulations would be conducted by algorithms of the shortest time-consuming method and double hierarchical model. By comparison of those results, the feasibility of double hierarchical model could be test. Given that there are 3 types of supplies at 4 supply sites offered to 4 fault sites which need rescue in an emergency repair scheduling of power grid, the reserve amount of supplies, the demand amount of supplies and the transportation time would be given by the method of random number to simulate all possible sudden situations in practice. The relationship between supply sites and demand sites is shown in Figure 2 below.

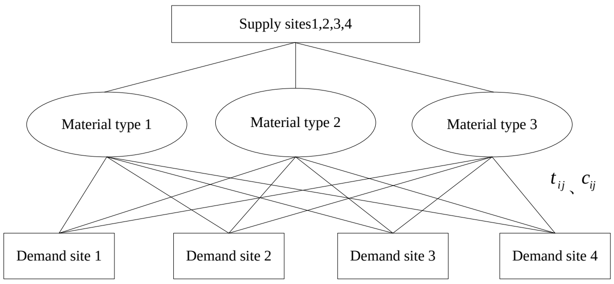

FIGURE 2 Relationship between supply sites and demand sites in emergency scheduling system

Transportation Time t_{ij} is set as a random number in the interval of [6, 20], Transportation Cost c_{ij} is assigned as a random number in the interval of [2, 10], Supplies Reserve A_{ki} at supply sites is a random number in the interval of [15, 45] and demand Supplies B_{kj} at demand sites is a random number in the interval of [10, 40]. If there is $\sum_i A_{ki} < \sum_i B_{kj}$, then random numbers should be reset. The scale of population is 50 with the crossover possibility of $P_c = 0.85$ and the mutation possibility of $P_r = 0.07$, and the limitation of transportation time T_m should be set by considering the severity at fault sites and the practical transportation time from supply site i to demand site j. Therefore, the limitation time would be given by experts, which is $T_m = 10$ in this paper. If there is a solution under this limitation, there are $\lambda_1 = 0$ and $\lambda_2 = 1$, or the objective would shift into the shortest transportation time. Since there are differences between transportation cost and transportation time on both magnitude and significance, coefficients should be set after fully considering experts' advice [11, 12], which are $\lambda_1 = 10/(10+1)$ and $\lambda_2 = 1/(10+1)$ here. In terms of Matlab, the above process would work out two sets of data on the amount of supplies at both supply sites and demand sites, consumed time, and cost as shown in Table 1 below.

TABLE 1 The amount of supplies, consumed time and cost

Parameter	Situation1	Situation 2
A_{ik}	35,27,30 26,37,18 24,31,39 26,30,38	25,39,34 27,40,23 26,23,25 30,28,38
B_{jk}	20,30,34 33,28,19 18,35,29 35,27,23	24,30,14 14,16,22 21,12,15 13,26,17
t_{ij}	12,14,11,8 7,11,12,18 13,12,6,15 12,10,11,12	10,7,10,6 13,5,8,10 9,12,5,10 8,14,8,15
c_{ij}	2,3,5,8 4,5,7,2 1,4,6,7 2,5,7,3	3,5,7,9 6,8,6,4 7,6,7,3 7,6,5,10

In situation 1, when transportation time is longer than T_m at the least loss, the results of simulation are listed in Table 2. Under the same preconditions, the optimal solutions for two algorithms are the same, i.e., the shortest transportation time is 12 and the transportation cost is $\sum_{i,j} c_{ij}\left(\sum_k x_{kij}\right)=1853$, which means that two algorithms are equally accurate in this situation.

TABLE 2 Optimal solutions for two algorithms in situation 1

Algorithms	Shortest transportation time	Optimal solution x_{kij}
Genetic algorithm	12	$x_{141}=35$ $x_{142}=27$ $x_{143}=23$ $x_{211}=20$ $x_{212}=30$ $x_{213}=18$ $x_{331}=18$ $x_{332}=31$ $x_{333}=29$ $x_{421}=26$ $x_{422}=28$ $x_{423}=19$ $x_{221}=6$ $x_{432}=2$ $x_{413}=3$ $x_{232}=2$ $x_{321}=1$
Double hierarchical genetic algorithm	12	$x_{141}=35$ $x_{142}=27$ $x_{143}=23$ $x_{211}=20$ $x_{212}=30$ $x_{213}=18$ $x_{331}=18$ $x_{332}=31$ $x_{333}=29$ $x_{421}=26$ $x_{422}=28$ $x_{423}=19$ $x_{221}=6$ $x_{432}=2$ $x_{413}=3$ $x_{232}=2$ $x_{321}=1$

In situation 2, when the limiting condition of $T<T_m$ is met, the objective function would be solved to find out the least transportation cost and the results of simulation are listed in Table 3. When the shortest transportation time for two algorithms are all within the limitation of 10, there are $C_1=\sum_{i,j} c_{ij}\left(\sum_k x_{kij}\right)=1732$ for Genetic algorithm and $C_2=875$ for double hierarchical genetic algorithm, which shows that double hierarchical genetic algorithm is obviously superior to genetic algorithm on expenditures.

TABLE 3 Optimal solutions for two algorithms in situation 2

Algorithms	Shortest transportation time	Optimal solution x_{kij}
Genetic algorithm	9	$x_{221}=14$ $x_{222}=16$ $x_{223}=22$ $x_{331}=21$ $x_{332}=12$ $x_{333}=15$ $x_{141}=13$ $x_{142}=26$ $x_{143}=17$ $x_{411}=24$ $x_{412}=28$ $x_{413}=14$ $x_{312}=2$
Double hierarchical genetic algorithm	10	$x_{111}=24$ $x_{112}=30$ $x_{113}=14$ $x_{341}=13$ $x_{342}=23$ $x_{343}=17$ $x_{242}=3$ $x_{221}=14$ $x_{222}=16$ $x_{223}=22$ $x_{431}=21$ $x_{432}=12$ $x_{433}=15$

It shows in the two tables above that when transportation time is longer than the time constraint at the least loss, the results of the shortest transportation time are the same for two algorithms, and when the condition of minimal time constraint is met, the value of objective function's solution for double hierarchical genetic algorithm decreases since the objective function takes the least transportation cost as the main factor, while for genetic algorithm, the shortest transportation time is still the objective of the solution with amount of transportation cost. In comparison, double hierarchical genetic algorithm is better than single objective genetic algorithm.

6 Conclusions

According to the nature of power grid supplies planning, a hierarchical genetic algorithm is proposed to make a planning for emergency scheduling and path selection in this paper. Based on genetic algorithm and with double hierarchical objective function set by weights, this algorithm could iterate to find out the optimal solution for supplies scheduling & planning at the least loss after an accident when the inequality constraints are met. In a study case, it shows that the hierarchical genetic algorithm could effectively decrease economic loss of an accident under the limitation of time. We believe this method could be widely used in power grid emergency supplies scheduling.

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