

A multi-group ant colony algorithm-based method for planning emergency repair tasks for electrical equipment

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Abstract: The electrical system is composed of multiple types of equipment such as power plants, substations, transmission lines, distribution systems and loads, etc. Different equipment corresponds to different maintenance strategies, so for multiple types of electrical equipment emergency repair task planning problems, this paper proposes a method that uses a multi-group ant colony algorithm to solve the problem considering factors such as equipment importance, task threat, path distance and repair operation time, and uses the method to carry out case simulation. In the simulation experiment of planning the task planning of 25 electrical equipment emergency repair in 3 categories with a time of 5.2 seconds, the research results show that the algorithm can quickly solve to get the task assignment and route order of the equipment emergency repair group with feasibility and rationality.

Keywords: Power Equipment, Emergency Repair, Task Planning, Multi-Group Ant Colony Algorithm

1. Questions to Ask

Electric power facilities are an important basic engineering facility system that sustains urban functions and regional socioeconomic functions in modern society^[1]. Large-scale power system failures usually originate from the impact of natural disasters and present the characteristics of multi-point dispersion of faulty facilities and equipment^[2]. Therefore, it is necessary to orderly dispatch repair forces to repair damaged facilities and equipment scientifically and efficiently according to the damaged power facilities after the disaster to minimize losses and guarantee economic and social benefits, while the risk of the task process should be guaranteed to be controllable^[3].

In order to improve the scientific nature of power repair task planning, Zhang Mingquan et al.^[4] established an optimal repair path model for power communication networks and studied the application of improved discrete particle swarm algorithm in the optimal repair path. Zhaoli Gao et al.^[5] established an optimization model for multi-point fault emergency repair of distribution network with comprehensive consideration of repair resource allocation, improved the traditional artificial bee swarm algorithm, and proposed a unified scheduling method. Meng Rong et al.^[6] improved the particle swarm algorithm (PSO) by introducing dynamic inertia weights, and conducted an optimization study on the objectives of emergency repair sequencing scheme and reducing the deployment time of repair work. However, the aforementioned studies mainly optimize the objectives such as path and time spent in the planning of repair tasks, but do not consider enough aspects such as the importance of different equipment to be repaired and the risk factors in the process of performing repair tasks.

The multi-group ant colony algorithm divides the ant colony into multiple groups, each group has a certain number of ants, and achieves the purpose of fast search for the optimal solution through mutual collaboration and parallel search of multiple groups of ants.

In this paper, the task planning of post-disaster multi-type power repair force will be studied and solved by using multi-group ant colony optimization algorithm, in order to provide some theoretical basis and practical reference for post-disaster power repair auxiliary decision and power repair command system development.

2. Model Construction

2.1. Model Background

After earthquakes, landslides, heavy rainfall and other natural disasters, there are S types of electric equipment to be repaired, and their numbers are N_1, N_2, \dots, N_s , totaling N units. The location distribution of the equipment to be repaired is P_1, P_2, \dots, P_n , its importance is assessed by the technical information department as I_1, I_2, \dots, I_n , and its expected repair operation time is analyzed by the technical information department's prediction as T_1, T_2, \dots, T_n .

The power equipment repair center is located at the rear P_0 . There are S types of professional equipment repair groups, whose numbers are M_1, M_2, \dots, M_s , totaling M groups. The equipment repair groups drive the corresponding equipment repair vehicles to motorize to the location of the equipment to be repaired.

To be repaired between the equipment P_i and P_j path nearest distance is simplified as a straight line recorded as D_{ij} , the road was accidental geological hazards and other tasks threatened by geological, meteorological information department to assess the degree of R_{ij} , each professional equipment repair group travel are uniform speed v .

2.2. Objective Function

With diverse planning situations and complex influencing factors, emergency repair tasks need to always be pursued with the goal of improving economic efficiency while preventing risks. Therefore, this paper establishes a multi-species multi-shift repair task planning model with two objective functions of minimizing the sum of equipment loss due to waiting for repair and minimizing the impact of task threat during the repair maneuver as the optimization objectives.

Objective 1: the maximum economic benefits of repair, that is, the importance of all equipment and the minimum sum of losses due to the product of repair waiting time, so that the importance of high equipment as far as possible in front of the repair, the short path as far as possible in front of the repair, repair time as short as possible in front of the repair, the model mathematical description as follows.

$$\text{Min}Z = \sum_{s=1}^S \sum_{m=1}^{M_s} \sum_{n=1}^{N_{M_s}} I_{n_{m_s}} t_{n_{m_s}} \quad (1)$$

Where, S is the number of equipment types, M_s is the number of equipment repair groups corresponding to that type of equipment, and N_{M_s} is the number of equipment repaired by each repair group corresponding to that type of equipment.

The waiting time t_i for a single piece of equipment to be repaired is: the time that the i th equipment repair task waits for a similar equipment repair team to arrive at the implementation site from the starting point, i.e., the repair team completes the previous $i-1$ equipment repair operation time and the time consumed through the path.

$$t_i = \sum_{n=1}^i \left(\frac{D_{nm}}{v} + T_n \right) \quad (2)$$

Objective 2: The task threat level impact minimum is the minimum sum of the threat level on the path passed by all types of equipment repair teams, so that the equipment repair team in the course of the task to minimize the risk.

$$\text{Min}W = \sum_{s=1}^S \sum_{m=1}^{M_s} \sum_{n=1}^{N_{M_s}} R_{ij} X_{ij} \quad (3)$$

R_{ij} is the threat degree of the path passed between the equipment to be repaired i and j . X_{ij} indicates the possibility of the professional equipment repair group of the type to choose to go to the repair equipment j after completing the repair task i . $X_{ij}=0$ means no choice; $X_{ij}=1$ means choice, $i, j \leq N_s$.

2.3. Model Principle

Ant colony intelligence optimization algorithm (ACO)^[7] is a colony intelligence heuristic algorithm, which is based on the observation of ants, a typical swarming organism in nature. This positive information feedback mechanism allows the colony to find food sources quickly in multiple foraging paths, demonstrating complex social attributes and group intelligence. The optimal search strategy of the ant colony algorithm consists of two key components: first, heuristic information, which is mainly based on short-term visible local objectives; and second, pheromone concentration, which is mainly based on global information from historical experience.

The heuristic information was calculated as follows

$$n_{ij} = \frac{I_j}{R_{ij} \times (D_{ij} / v + T)} \quad (4)$$

The pheromone update method is.

$$\Delta \tau_{ij}(t+1) = \rho \cdot \tau_{ij}(t) + \Delta \tau_{ij}(t) \quad (5)$$

$$\Delta \tau_{ij} = \sum_{k=1}^m \Delta \tau_{ij}^k \quad (6)$$

$$\Delta \tau_{ij} = \begin{cases} \frac{Q}{Z_k^\delta \times W_k^\varepsilon} & \text{The } k\text{-th ant passes through node } ij \text{ in this cycle} \\ 0 & \text{The } k\text{-th ant does not pass through node } ij \text{ in this loop} \end{cases} \quad (7)$$

Where Q represents the total amount of pheromones as a constant, ρ denotes the volatility coefficient and $\rho \in [0, 1]$, $\Delta \tau_{ij}^k$ denotes the pheromones left by the k th ant on the path, Z_k denotes the sum of the importance of the loss of the k th ant in this cycle of the unpassed path due to waiting, W_k denotes the sum of the ants' threatening influence on the path, and δ and ε denote the correction power coefficients.

$$p_{ij}^k(t) = \begin{cases} \frac{\tau_{ij}^\alpha(t) \eta_{ij}^\beta(t)}{\sum_{s \in \text{allowed}} \tau_{is}^\alpha(t) \eta_{is}^\beta(t)}, & s \in \text{allowed} \\ 0 & , s \notin \text{allowed} \end{cases} \quad (8)$$

The above equation represents the probability of transferring ant k from node i to j at moment t . α is a constant indicating the importance of path pheromone and β is a constant indicating the importance of heuristic information, when node j is in the forbidden list then means cannot be repeatedly visited, so the transfer probability is 0.

3. Simulation Experiments

3.1. Experimental Background

In order to verify the feasibility of the algorithm, this paper uses a multi-group ant colony algorithm to plan the repair tasks in the context of an exercise scenario of power facility repair in response to a geological disaster in a region. According to this emergency repair exercise scenario, the equipment repair center received a total 25 of equipment repair tasks, including I equipment 12, II equipment 8 and III equipment 5, whose coordinate locations, importance, routes and threat degrees, scheduled task execution time and other related information have been summarized through the command information system, as shown in the Table 1.

Table 1: Data related to equipment repair tasks.

Equipment Category	Equipment Number	Equipment location/km		Importance	Expected repair work Time/h
		X	Y		
Class I equipment	T1	68	25	8	1
	T2	56	14	6	1.4
	T3	71	32	4	1.2
	T4	31	-9	3	0.7
	T5	32	3	7	0.9
	T6	51	25	4	1.6
	T7	62	-32	5	1.8
	T8	53	-20	3	0.8
	T9	63	-1	7	1.7
	T10	32	-5	5	1.1
	T11	75	-15	6	0.4
	T12	45	10	9	1.6
Class II equipment	P1	22	29	7	1.6
	P2	24	33	7	0.8
	P3	18	26	7	1.2
	P4	25	27	7	0.7
	P5	23	-29	4	1.5
	P6	23	-32	4	1.1
	P7	20	-25	4	1
	P8	25	-20	4	1.4
Class III equipment	D1	-10	3	6	1.5
	D2	1	9	6	1
	D3	-3	-6	6	0.8
	D4	5	7	6	0.5
	D5	10	-1	6	1.2

Now from the rear of the equipment repair center can be sent to the corresponding categories of equipment repair group number of 3 groups,2 groups, 1 groups, carrying relevant equipment and equipment, with 15km/h speed mobile to the equipment to be repaired geographical area.

The threat level between the repair paths of each type of equipment was assessed as shown in the Table 2.

Table 2: Equipment repair path threat degree.

	Class I equipmen												Class II equipment								Class III equipment					
	P0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	P1	P2	P3	P4	P5	P6	P7	P8	D1	D2	D3	D4	D5
P0	0	5	2	3	2	3	3	6	2	2	7	6	2	8	9	7	5	3	3	7	2	9	6	6	5	1
T1	5	0	7	8	1	9	3	6	6	8	1	2	3													
T2	2	7	0	5	4	4	5	6	4	1	8	3	3													
T3	3	8	5	0	7	6	9	9	2	9	5	4	5													
T4	2	1	4	7	0	8	1	1	7	5	2	9	7													
T5	3	9	4	6	8	0	4	1	2	1	7	6	5													
T6	3	3	5	9	1	4	0	6	4	4	5	3	8													
T7	6	6	6	9	1	1	6	0	7	7	4	3	3													
T8	2	6	4	2	7	2	4	7	0	4	1	4	2													
T9	2	8	1	9	5	1	4	7	4	0	7	6	6													
T10	7	1	8	5	2	7	5	4	1	7	0	6	3													
T11	6	2	3	4	9	6	3	3	4	6	6	0	6													
T12	2	3	3	5	7	5	8	3	2	6	3	6	0													
P1	8													0	8	2	4	6	4	6	6					
P2	9													8	0	3	6	1	1	7	2					
P3	7													2	3	0	7	1	4	4	9					
P4	5													4	6	7	0	3	5	4	2					
P5	3													6	1	1	3	0	5	7	8					
P6	3													4	1	4	5	5	0	3	7					
P7	7													6	7	4	4	7	3	0	5					
P8	2													6	2	9	2	8	7	5	0					
D1	9																					0	9	1	5	9
D2	6																					9	0	6	2	7
D3	6																					1	6	0	1	4
D4	5																					5	2	1	0	8
D5	1																					9	7	4	8	0

3.2. Simulation Results

According to the planning model of the emergency repair task of the equipment repair center, simulation experiments are conducted for the above-mentioned arithmetic cases. The final task planning results and the Gantt charts for each group of task planning are shown in Fig.1.

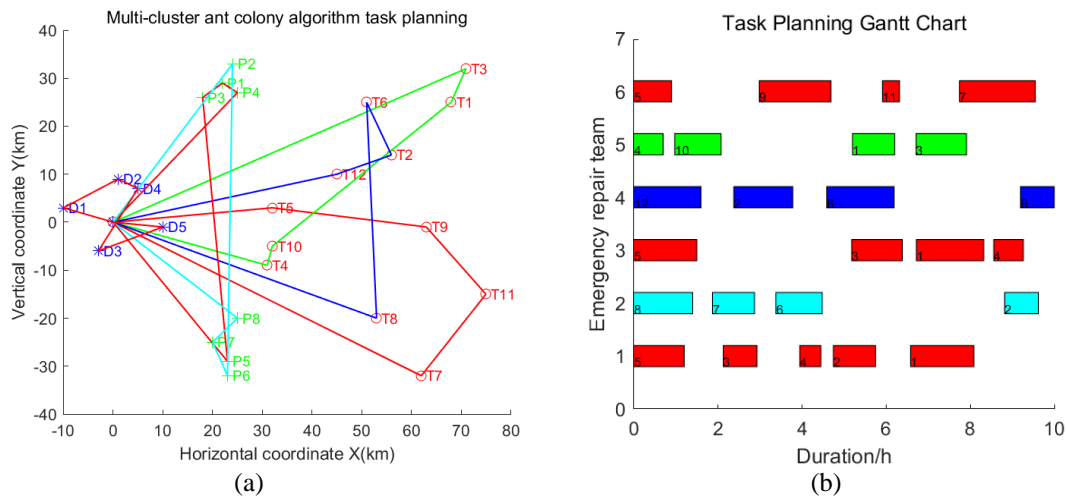


Figure 1: The result of emergency repair task planning chart.

The initialization parameters are set as follows: the pheromone importance degree factor α is 1, the heuristic function importance degree factor β is 5, the total pheromone constant Q is 50, the pheromone volatility coefficient Rho is 0.1, the correction weight coefficients δ and ε are 1, the simulation iterations 400, each generation runs 10 round.

3.3. Analysis of Simulation Results

After using the multigroup ant colony algorithm for the electric repair planning problem, we can obtain multiple iteration curves of the loss benefit of the corresponding type of equipment repair group. The order of the repair paths assigned to each type of equipment repair group is shown in the Table 3.

Table 1: Repair path order.

Emergency repair team	Path order	Loss of benefits
Class I equipment repair 1team	T5→T9→T11→T7	649
Class I equipment repair 2team	T4→T10→T1→T3	357
Class I equipment repair 3team	T12→T2→T6→T8	462
Class II equipment repair 1team	P5→P3→P1→P4	771
Class II equipment repair 2team	P8→P7→P6→P2	429
Class III equipment repair 1team	D5→D3→D4→D2→D1	491

4. Conclusion

In this paper, based on the consideration of the importance of electrical equipment, task threat, expected operation time and path distance in post-disaster electrical equipment repair, a multi-group ant colony algorithm is proposed to solve the repair task planning for multiple types of electrical equipment repair tasks by establishing a problem model, and the algorithm is verified by a electrical repair exercise scenario. The experimental results show that the algorithm can complete the computational convergence in a short time, and generate a visualization of the repair path and Gantt chart for easy interaction.

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