Joint Equipment Support Task Assignment Model and Simulation Based on Genetic Algorithm

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Abstract: With the transformation of the war pattern under the information conditions, the corresponding object of equipment support also changes from "equipment-oriented" to "warfare-oriented", and the equipment implement the joint support. Based on the characteristics of the equipment support task under the system combat conditions, the Joint Equipment Support task assignment model with the shortest transition time is established, and a model algorithm based on genetic algorithm is proposed. The validity and accuracy of the model and the algorithm are verified by the example simulation.

1 Introduction

At present, in order to adapt to the trend of the change of war pattern, and to improve combat effectiveness, the world army carry out the adjustment and reform of the military system[1][2]. This adjustment and reform shows that the future pattern of warfare will be transformed from single soldier operations to joint operations and system operations, and the object of equipment protection closely related to it will be changed from "equipment-oriented" to "warfare-oriented", and implementation Joint Equipment Support.

Joint Equipment Support is to deploy all the safeguarding forces and resources in the combat area by the Joint Support Command, the support forces deploy adopt "modular combination" method to form a temporary support team to implement equipment support according to support task. At present, there are many studies on the allocation of equipment support tasks and

the ensemble of support forces [3][4], but most of the models are not suitable for the practical application of the joint equipment support of regional operations and system operations under modern high-tech conditions. Therefore, arming at the characteristics of the joint equipment support in theater, how to establish the support force model which fit the support task demand from the numerous support forces is the key for commander of wartime equipment support to make the accurate guarantee decision-making.

2 Equipment Support Task Assignments Model

2.1 Basic conditions and assumptions of equipment support tasks

Considering the real conditions that a multi-combat unit needs to be supported at the same time, and each combat unit has many professional equipment or parts needs to be supported, the support personal belonging to a single support task can be divided into multiple

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support groups to implement according to the different organizations, levels and professional skills, the proposed definition and assumptions of air defense and anti-missile equipment support force grouping problem are as follows:

(1)Support tasks B_{ij} : All safeguards for maintenance, electrical inspection, troubleshooting and replacement of parts of a weapon unit shall be called a safeguard task. Support tasks of different operational direction have different priority, and the support task of key combat direction should be considered as priority.

(2)Support Team T_i : The minimum professional equipment support unit which is composed of different levels of professional members that taken from the safeguard module of the security force system, known as the protection group. The support group can complete a variety of maintenance tasks, different support groups will take different time for the same support tasks.

(3)There is a sequence of operations among all the support tasks of any combat unit, and there is no sequence of support tasks between different combat units.

(4)Each support group can only operate one support task at any time. Each support task of any combat unit can be operated by only one support group at any time of protection.

(5)Without loss of generality, it is assumed that each support task of each fire unit, once started, cannot be interrupted.

2.2 Problem description

In joint operation, there may be multiple combat directions operations at the same time, so all the combat units of different direction are necessary to be support, and there is a prior act based on the priority of the different combat direction, when a support group finished a security task, can turn to support another combat unit, and ultimately complete all the tasks. Therefore, the problem of equipment support task assignment is to find the most scientific matching scheme for

support force and support task, including each combat unit for each security task to select the most appropriate protection group, each group needs to determine the best sequence for the support task set, and once each support task start, it should complete all the tasks of combat units in the shortest possible time.

2.3 Support task allocation model

According to the above description of the equipment support task and the description of the problem of the task assignment, the task assignment model is established as follows:

Objective function:

$$\min \left(\max_{i \in [1, \dots, I]} (t_i) \right) \quad (1)$$

Which is subject to

$$\sum_{i=1}^I x_{ij}^k = 1, j = 1, 2, \dots, J, k = 1, 2, \dots, h_j \quad (2)$$

$$x_{ij}^k = \begin{cases} 1, & s_{ij}^k \neq 0 \\ 0, & s_{ij}^k = 0 \end{cases} \quad (3)$$

$$0 \leq s_{ij}^k \leq \sum_{j=1}^J h_j \quad (4)$$

$$s_{ij}^k \in Z, \quad Z \text{ is a natural number} \quad (5)$$

The objective function of Eq. (1) represents the shortest time to complete the task. Eq.(2) indicates that at any one time, each support group can only perform a support task; Eq.(3) shows the order of the k -th task in the task sequence of support task group T_i . Eq.(4) indicates that the task sequence number of the support group cannot be greater than the total sequence number of the guaranteed task.

In the objective function, t_i is the total time for support group T_i to finish the support task. The priority weights of the different combat directions is expressed, and is calculated within the guarantee time, the support time in the calculation formula also includes the transition time of the support unit from a certain place to the supported unit.

$$t_i = at_{ij} + \sum_{n=1}^m st_{jn}^{k_n} + \sum_{n=2}^m zt_{jn-1jn} \quad (6)$$

Where, at_{ij} represents the arrival time of the support team T_i from its support base to the combat unit B_j . $st_{jn}^{k_n}$ represents the support time of support task B_{jk} that the support group T_i on the combat unit B_{jk} . zt_{ij} represents the time of combat unit B_i transport to B_j .

3 Genetic algorithm for support task assignment model

As a widely used intelligent optimization method, Genetic algorithm (GA) is applied to solve the discrete combinatorial optimization problems [5-7]. Based on the genetic mutation between individuals and the natural selection mechanism of the tournament, the paper designs the coding/decoding and fitness function for the grouping problem of support forces, and obtains the most scientific task assignment scheme.

3.1 Algorithm flow

Based on the evolutionary mechanism of genetic algorithm and iterative optimization, this paper designs the algorithm for solving the task assignment optimization problem of the air defense and anti-missile equipment maintenance team as shown in Fig.1.

Fig.1. Algorithm process of support task assignment

The key points of the algorithm: First, through great coding and decoding rules, building a seamless transition between the construction of the support power grouping scheme and the feasible solution of the genetic evolution operation. Second, design the simple and scientific calculation method of the objective function, generate the fitness of each

individual in the population genetic evolution operation by the support force grouping scheme.

3.2 Encoding and decoding rules

According to the characteristics of the equipment support task assignment problem, we assume that the input of support task is shown in Table.1.

Table 1. Input of maintenance support task problem

task	B_{11}	B_{12}	B_{13}	B_{21}	B_{22}	B_{23}
T_1	1.5	2	∞	∞	1.5	∞
T_2	2	∞	3	2.5	∞	3
T_3	1	1.5	∞	2	2	∞
T_4	∞	∞	2	∞	2.5	2

A non-zero number in the table indicates the time that the support team performed the corresponding support task, and “ ∞ ” indicates that the corresponding task cannot be performed.

The design code is to be able to clear the only refers to the support group corresponding to all maintenance tasks in the sequence of operations. And the design code is to be able to refer to the only support group for each task.

Therefore, according to the characteristics of the task assignment problem of equipment support, this paper proposes a two-level coding rule based on the maintenance support task and the maintenance support group with the natural number serial number coding, and is illustrated by a simple example, as shown in Table.2.

Table 2. Feasible solution of support group scheme

Task	B_1	B_1	B_1	B_2	B_2	B_2
First layer code	1	3	4	2	1	2
Second layer code	2	1	1	1	1	2

The first layer code is used to refer to the support group label corresponding to each safeguard task; the second layer code is the task sequence number for the support task in the corresponding support group.

Decoding rules: Confirm the support group corresponding to the support task force according to the security group label, and then, confirm the order of implementation according

to the support task sequence number of support group. In this way, we can know the tasks of the support group T_1 and its order $B_{22} \rightarrow B_{11}$, the support group T_2 and its order B_{21} , the support group T_3 and its order B_{12} , the support group T_4 and its order B_{13} .

3.3 Fitness value calculation

The purpose of support force marshaling is to minimize the total support time, so the Eq. (1) is used as the fitness value of the chromosome to realize the individual evaluation and ranking.

3.4 Select, crossover and mutate operations

Genetic Algorithm(GA) is selected by the roulette wheel operation, select the next generation of iterative evolution of the population of individuals, the selected individuals which participate in the next generation of evolution must be a large fitness of individuals, and the greater the fitness, the larger the chance, the size of the area represents this chosen opportunity.

Crossover operation is the most important step in GA. The new generation can be obtained by crossing, which can combine with the excellent gene of the parent individual. Because of the method with double layer encoding and sequence in this paper, the genetic crossover operation adopts the same level independent crossover method, the genetic cross-operation using the same level of independent crossover method, as shown in Fig.2.

Fig.2. Double layer independent crossover

In Fig.2, the position of the arrow is the crossover point. Here two-point crossover method is selected.

After the new individuals are obtained by crossover and mutation operations, check its feasibility through the Eq. (2) - (4) and the initial input, if not satisfied, repeating the selection, crossover and mutation operations.

After several iterations, we can obtain the optimal support task assignment scheme and the order and time for different teams to accomplish different tasks.

4 Simulation analysis

4.1 Simulation case

Suppose that there has a support group consisting of 10 support units in the combat area, there are 6 combat units need to be supported. In order to verify the reasonableness of the algorithm, set 6 support tasks for each combat unit, and each support task optional maintenance group set and the time of maintenance group to complete the corresponding maintenance task as shown in Table.3.

In Table.3, combat unit 3 and combat unit 4 as the main combat direction that supported by priority. Combat units 1,2,5,6 as the non-combat direction combat unit. The maintenance support tasks are represented by the subscript of combat units, such as the subscript digit “12” of “ B_{12} ” means the second support task of combat unit 1, but even the second digit of the different combat units subscript are same, does not mean that the same type of support tasks. Each support group and the corresponding digital of maintenance task in the table represent the time of the support group to complete the task, “ ∞ ” means that the support group can't complete the maintenance task. The difficulty, quota size of the task and the ability of the support group to support different tasks are indicated by different maintenance time.

Table 3. Input data of equipment maintenance support task example

Task	support group set (time of complete the repair task)									
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
B_{11}	∞	∞	1.5	∞	∞	∞	∞	∞	∞	2.5
B_{12}	5	∞	∞	∞	∞	∞	∞	∞	∞	∞
B_{13}	∞	4.5	∞	∞	∞	∞	∞	∞	∞	∞
B_{14}	∞	∞	∞	2.5	∞	∞	2	∞	∞	∞
B_{15}	∞	∞	∞	∞	∞	1.5	∞	1.5	∞	∞
B_{16}	∞	∞	∞	∞	5	∞	∞	∞	∞	∞
B_{21}	∞	3	∞	∞	∞	∞	∞	∞	∞	∞
B_{22}	∞	∞	4	∞	∞	∞	∞	∞	∞	∞
B_{23}	∞	∞	∞	∞	0.5	∞	∞	2	∞	∞
B_{24}	∞	∞	∞	∞	∞	2.5	3	∞	∞	∞
B_{25}	1.5	∞	∞	∞	∞	∞	∞	∞	∞	1.5
B_{26}	∞	∞	∞	1.5	∞	∞	∞	∞	∞	1.5
B_{31}	∞	∞	0.5	∞	∞	∞	∞	∞	2	∞
B_{32}	∞	∞	∞	2.5	∞	∞	3.5	∞	∞	∞
B_{33}	∞	∞	∞	∞	∞	2.5	∞	3	∞	∞
B_{34}	2.5	∞	∞	∞	∞	∞	∞	∞	∞	∞
B_{35}	∞	4.5	∞	∞	∞	∞	∞	∞	∞	5.5
B_{36}	∞	∞	∞	∞	0.5	∞	∞	∞	∞	∞
B_{41}	∞	∞	∞	3.5	∞	∞	∞	∞	∞	∞
B_{42}	2	∞	∞	∞	∞	∞	∞	∞	1.5	∞
B_{43}	∞	∞	2	∞	∞	∞	3	∞	∞	∞
B_{44}	∞	1.5	∞	∞	∞	∞	∞	2.5	∞	∞
B_{45}	∞	∞	∞	∞	0.5	∞	∞	∞	∞	∞
B_{46}	∞	∞	∞	∞	∞	1.5	∞	∞	∞	∞
B_{51}	∞	∞	∞	∞	3	∞	∞	∞	∞	∞
B_{52}	∞	5	∞	∞	∞	∞	6	∞	∞	∞
B_{53}	∞	∞	3.5	∞	∞	∞	∞	∞	∞	4.5
B_{54}	∞	∞	∞	∞	∞	4	∞	∞	4	∞
B_{55}	2.5	∞	∞	∞	∞	∞	∞	∞	∞	∞
B_{56}	∞	∞	∞	2	∞	∞	∞	3.5	∞	∞
B_{61}	∞	1	∞	∞	∞	∞	∞	∞	∞	∞
B_{62}	∞	∞	∞	2	∞	∞	3.5	∞	∞	∞
B_{63}	∞	∞	∞	∞	∞	3	∞	∞	4.5	∞
B_{64}	0.5	∞	∞	∞	∞	∞	∞	∞	∞	∞
B_{65}	∞	∞	∞	∞	2.5	∞	∞	4	∞	∞
B_{66}	∞	∞	1.5	∞	∞	∞	∞	∞	∞	∞

The arrival time from the support base to each combat unit is indicated by the vector AT .

$$AT = [1.5 \ 2 \ 1.5 \ 2.5 \ 1.5 \ 2]$$

The transition time matrix ZT between combat units is

$$ZT = \begin{bmatrix} 0 & 1 & 1.5 & 2 & 1 & 1.5 \\ & 0 & 2 & 2.5 & 1.5 & 1 \\ & & 0 & 1.5 & 1 & 1.5 \\ & & & 0 & 2 & 2.5 \\ & & & & 0 & 1.5 \\ & & & & & 0 \end{bmatrix}$$

According to the optimization model and solving algorithm, the simulation results are shown in Fig.3 and Table.4.

Fig.3. Optimization curve of iterative algorithm

Table.4 Maintenance task assignment results

Combat Unit No.	Task	Support Group	Task Sequence	Task Start Time	Task End Time
Unit 1	B_{11}	T_{10}	1	1.5	4
	B_{12}	T_1	1	1.5	6.5
	B_{13}	T_2	3	8	12.5
	B_{14}	T_7	3	14.5	16.5
	B_{15}	T_6	2	5.5	7
	B_{16}	T_5	4	10	15
Unit 2	B_{21}	T_2	4	13.5	16.5
	B_{22}	T_3	2	4	5
	B_{23}	T_8	1	2	4
	B_{24}	T_6	3	7	9.5
	B_{25}	T_{10}	3	13	14.5
	B_{26}	T_{10}	4	14.5	15
Unit 3	B_{31}	T_3	1	1.5	2
	B_{32}	T_4	1	1.5	4
	B_{33}	T_6	1	1.5	4
	B_{34}	T_1	2	8	10.5
	B_{35}	T_{10}	2	5.5	11
	B_{36}	T_5	2	5.5	6
Unit 4	B_{41}	T_4	2	5.5	9
	B_{42}	T_9	1	2.5	4
	B_{43}	T_7	1	2.5	5.5
	B_{44}	T_2	1	2.5	4
	B_{45}	T_5	3	7.5	8
	B_{46}	T_6	4	12	13.5
Unit 5	B_{51}	T_5	1	1.5	4.5
	B_{52}	T_7	2	7.5	13.5
	B_{53}	T_3	3	9.5	13
	B_{54}	T_9	3	12.5	16.5
	B_{55}	T_1	4	14.5	16.5
	B_{56}	T_8	3	10.5	14
Unit 6	B_{61}	T_2	2	6	7
	B_{62}	T_4	3	11.5	13.5
	B_{63}	T_9	2	6.5	11
	B_{64}	T_1	3	12.5	13
	B_{65}	T_8	2	5	9
	B_{66}	T_3	4	14.5	16

4.2 Simulation results and discussions

According to the optimization algorithm, we obtain the optimal maintenance support power grouping scheme of the study example.

In this study, the order and the total time for each support group to complete the maintenance tasks are:

Support Group T_1 : $B_{12} \rightarrow B_{34} \rightarrow B_{64} \rightarrow B_{55}$, task completion time: 16.5.

Support Group T_2 : $B_{44} \rightarrow B_{61} \rightarrow B_{13} \rightarrow B_{21}$, task completion time: 16.5.

Support Group T_3 : $B_{31} \rightarrow B_{22} \rightarrow B_{53} \rightarrow B_{66}$, task completion time: 16.

Support Group T_4 : $B_{32} \rightarrow B_{41} \rightarrow B_{62}$, task completion time: 13.5.

Support Group T_5 : $B_{51} \rightarrow B_{36} \rightarrow B_{45} \rightarrow B_{16}$, task completion time: 15.

Support Group T_6 : $B_{33} \rightarrow B_{15} \rightarrow B_{24} \rightarrow B_{46}$, task completion time: 13.5.

Support Group T_7 : $B_{43} \rightarrow B_{52} \rightarrow B_{14}$, task completion time: 16.5.

Support Group T_8 : $B_{23} \rightarrow B_{65} \rightarrow B_{56}$, task completion time: 14.

Support Group T_9 : $B_{42} \rightarrow B_{63} \rightarrow B_{54}$, task completion time: 16.5.

Support Group T_{10} : $B_{11} \rightarrow B_{35} \rightarrow B_{25} \rightarrow B_{26}$, task completion time: 15.

It can be seen that the latest task completion time of all the support groups in this support power is 16.5, and the earliest task completion time is 13.5.

Through the analysis of the optimal support force marshaling program, the maintenance task latest completion time of combat unit 3 in the important direction is 11, the maintenance task completion time of combat unit 4 is 13.5. The maintenance task latest completion time of combat unit 1 in non-important direction is 16.5. The maintenance task latest completion time of combat unit 2 is 16.5. The maintenance task last completion time of combat unit 5 is 16.5. The maintenance task latest completion time of combat unit 6 is 16. In this example, the maintenance task latest completion time of combat unit 3 and 4 in important direction are shorter than the combat units in non-important combat direction, which shows that the task assignment scheme is meets the requirement that the mission priority of the important direction and the non-important direction comes second. And the feasibility and validity of the proposed model and algorithm are verified.

5 Conclusion

The support task allocation model is based on the fact that the regional support forces are all set up in a support base, and the total support time is the support group from the support base to the supported combat units, also include the transition time from one operational unit to another when a task was finished. The model takes into account the importance of the combat units in different combat directions, and the difficulty, quota size of the task and the ability of the support group to support

different tasks are indicated by different maintenance time. The factors considered in the model are similar to those of the actual support forces, and the model is practicality.

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