Solving Dynamic Logistic Problem in Equipment Support Area

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Abstract. We proposed a novel method for dynamic logistic problem in the process of equipment support. Firstly, a multi agent system framework is built, including task agent, resource agent, negotiation agent and monitoring agent. In the static and dynamic logistic problems, we used a hybrid genetic tabu search (HGTS) algorithm, which decomposes the abstracted MRCPSP problem into MAP and RCPSP problems and dealt with them separately. The logistic problem cannot be solved until the modes of each task are assigned. The simulation experiments have proved that the proposed HGTS algorithm has better average deviation and optimal solution ratio than those of the traditional genetic algorithm and particle swarm optimization algorithm, which reflects the stability and calculation quality of the algorithm.

Keywords: dynamic logistic; multi agent system; equipment support; MRCPSP.

1. Introduction

Equipment support is a general term for various safeguard measures and command activities adopted by the military to enable the needed equipment to successfully complete various tasks. By optimizing the dynamic logistic of equipment, it can effectively improve the use efficiency of equipment maintenance resources especially in wartime, greatly shorten the average waiting time of weapons and equipment, restore the combat capability of equipment in a short time, and win the initiative for war. Therefore, it is of great significance to carry out dynamic logistic optimization research to improve equipment support capability and restore combat unit combat capability as soon as possible. The essence of equipment support is to make effective use of limited manpower and material resources for a certain period of time and completed within the space [1, 2]. Dynamic logistic management refers to the maximum resource availability under resource-constrained conditions, and resource allocation according to the importance and priority of the task.

2. Related Work

Improving the ability to equipment support has always been the focus of research by national military forces. Xavier et al. use the Reinforcement Learning algorithm to achieve an autonomous allocation of resources in the cloud [3]. Koehler and Benkner have built resource allocation architecture in a cloud computing environment that relies on utility data and a utility function that ranks the costs of different configurations of resources to achieve an efficient allocation of cloud computing resources [4]. Pawltak Z established the spare parts cost function from the perspective of system availability and guaranteed probability to achieve optimization [5].

In terms of dynamic logistic, Li Junliang, Teng Ke et al. proposed an improved ant colony algorithm to simulate and optimize the shipboard helicopter maintenance optimization model, which effectively solved the long ship-to-ship period and the maintenance task time of the ship-borne helicopter during long-distance navigation [6]. Yan Xiaolong, Li Xianwen et al. applied the supporting analysis to explore the process of determining the equipment resources in active service [7]. Zhang Guowei et al. established a maintenance-based task logistic model and shortened the completion time of the entire maintenance task. Zhang Wenxiu, Qiu Guofang et al. performed the simulation modeling and optimization solution for maintenance support system [8].

This paper focuses on two aspects, the first part is to consider the priority order of maintenance tasks, so there are priority constraints between tasks, and a maintenance task needs to be completed after its immediate priority maintenance task is completed. Secondly, in the process of logistic, special emergency situations are taken into account, and then the functions of rescheduling and rearranging equipment support maintenance tasks are added.

3. Approach for Dynamic Logistic in Equipment Support Area

In the overall logistics process, this paper applies multi agent system (MAS), which includes task agents, resource agents, negotiation agents, and monitoring agents. They communicate with each other and report real-time changes, thus realizing logistic in a battlefield environment. The process of dynamic logistic is:

Step 1: the task agent analyzes the maintenance point and the corresponding maintenance task. The maintenance points have resource constraints, it is necessary to arrange the target maintenance points first, and arrange the logistics for maintenance equipment resources.

Step 2: After the equipment arriving at the maintenance point, the resource management agent performs logistic scheduling. There is more than one maintenance task which has their own priority orders, that is, these tasks need to be arranged have priority constraints.

Step 3: Monitor the first two steps of the agents. If there is no emergency, the monitor agent will be normal; but if there is an emergency, such as the maintenance point is attacked o cannot provide sufficient resources for equipment support, the situation needs to be reflected the negotiation agent. The information is fed back to the task agent by the negotiation agent, and all the resource schedules that are affected should be re-scheduled.

3.1 Architecture of Equipment Support Logistic System

The dynamic logistic based on equipment support problem is to monitor and efficiently coordinate the various resources encountered in the process of performing the task and complete the task in time. The details of agents' operation are shown in Fig. 1.

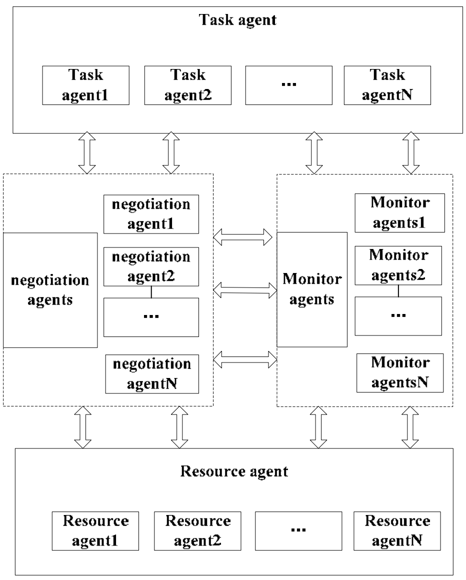

Fig. 1 MAS architecture of dynamic logistic

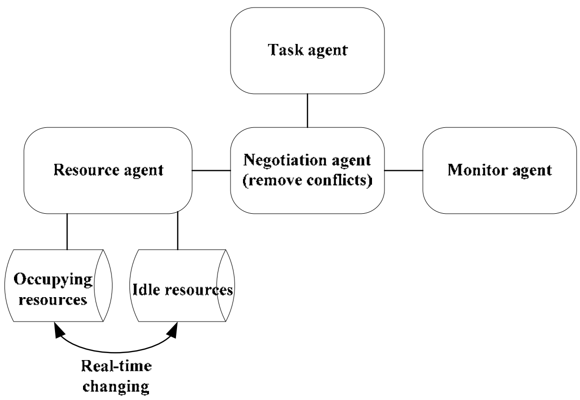

Fig.2 Working principle for dynamic logistic

The task agent records the related information of each task and is responsible for task assignment and feedback. The resource agent manages the resource information, records the resource busy state and displays the resource capability information. The negotiation agent coordinates the transmission and communication of tasks between the agents, besides, it also deals with resource conflicts between different tasks. As for monitoring agent, it plays the following roles, including monitoring tasks to perform Gantt chart information, performing performance analysis, providing decision support for other agents, and providing reference information for scheduling. The internal working principle can be seen in Fig. 2.

3.2 Logistic Algorithm

3.2.1 Problem Analysis

Equipment maintenance resources refer to renewable and non-renewable resources such as maintenance materials, personnel, maintenance funds associated with the equipment. The equipment maintenance is completed by the logistics personnel. In the battle scenario, multiple maintenance points will be arranged, each maintenance point is scattered everywhere, and their corresponding equipment and resources are different.

3.2.2 Modeling Method

We abstract this dynamic logistic problem into a multi-mode resource-constrained project scheduling problem (MRCPSP). Assuming that the total number of tasks of the equipment maintenance support project *V* is *J*, where *1* and *J+1* are two virtual tasks, and the other *J* tasks are subject to priority and resource constraints. Priority constraints mean that some maintenance tasks cannot be started until other tasks which have higher priority orders are already completed, while resource constraints indicate that the renewable and non-renewable resources are capacity limited.

Let a task i in the maintenance project select the m-th service point among the M_i modes to complete its operation, r^{ρ}_{imk} represents the k-th renewable resource is consumed, while r^{ν}_{imn} represents the n-th non-renewable resource, then d_{im} indicates the execution time of the i-th task. Time can be divided into discrete time units, T is the upper limit of the entire project, and EFi and LFi are the earliest start and the latest start time of task i, respectively.

This MRCPSP problem is mathematically modeled into the following formulas:

$$Min\ EF_J(\mathrm{x}) = \sum_{i=1}^{M_i} \sum_{t=EF_i}^{LFi} t \cdot x_{imt} \tag{1}$$

$$s.t. \qquad \sum_{m=1}^{M_i} \sum_{t=EF_i}^{LFi} x_{imt} = 1, i = 1,2,\cdots,J \tag{2}$$

$$\sum_{m=1}^{M_i} \sum_{t=EF_i}^{LFi} t \cdot x_{imt} \le \sum_{m=1}^{M_j} \sum_{t=EF_j}^{LF_j} (t - d_{jm}) \cdot x_{jmt}, j = 2,3,\cdots,J, i \in P_j \tag{3}$$

$$\sum_{i=1}^{J} \sum_{m=1}^{M_i} r^{\rho}_{imk} \sum_{q=max\{t,EF_i\}}^{min\{t+d_{im}-1,LFi\}} x_{imq} \le R^{\rho}_k, k = 1,2,\cdots,K, t = 1,2,\cdots,T \tag{4}$$

$$\sum_{i=1}^{J} \sum_{m=1}^{M_i} r^{\nu}_{imn} \sum_{t=EF_i}^{LFi} x_{imq} \le R^{\nu}_n, n = 1,2,\cdots,N \tag{5}$$

$$x_{imt} = \{0,1\}, i = 1,2,\cdots,J; m = i = 1,2,\cdots,M_i; t = EF_i,\cdots,LF_i \tag{6}$$

Equation (1) represents the objective function, that is, to minimize the duration, time needs to be divided into seconds on the battlefield; (2) means that each equipment can only select one mode, which means one maintenance point to perform one task; Equation (3) defines the priority constraint, task *j* can only start at the end of its last forward task *i*; formulas (4) and (5) are constraints of renewable resources and non-renewable resources, respectively. The renewable resource has a capacity limit at each moment, and the non-renewable resource cannot exceed the constraint on the total amount. The final formula (6) indicates that the maintenance point *m* is selected in task *i*, and is assigned a value of 1 when it is completed at the time *t*, 0 otherwise.

3.2.3 Dynamic Logistic Algorithm

The dynamic logistic problem, which is a typical NP-hard problem, requires that the logistic plan is optimized and the maintenance support duration is the shortest under the condition of meeting the priority and resource constraints. For this type of problem, the exact algorithm can only be solved in the small-scale problem, so we solve the problem through the heuristic algorithm. At present, the most popular algorithms include genetic algorithm, simulated annealing algorithm, tabu search algorithm, ant colony algorithm, etc.

For the dynamic logistic problem, we propose a hybrid genetic tabu search algorithm (HGTS). The basic genetic algorithm consists of three basic operators: selection, crossover, and mutation. The chromosomal group evolves in a better direction through a series of iterations and converges to the most adaptable individuals, finally obtains the optimal solution or satisfactory solution of the target problem.

Our idea is to convert MRCPSP to RCPSP in order to reduce the time to find a solution. In other words, we divide the MRCPSP into two steps: the mode allocation problem (MAP) and the RCPSP [9]. Once the mode has been determined, the more complex problem MRCPSP can translate into a less difficult and more typical RCPSP problem.

When solving the MAP problem, the genetic algorithm is applied. First, the chromosome is randomly generated. Suppose that there are 10 tasks in the total project, and each one has 3 modes, that is, there are 3 maintenance points. The encoded chromosome has 11 genes, the first 10 are randomly selected modes corresponding to 10 tasks, and the last one is the sum distances of all equipment maintenance reaching their maintenance points. As shown in Fig. 3, the modes of the first 10 tasks are 3, 2, 3, 1, 2, 1, 1, 1, 3, 2; the last gene calculates the sum of the distances, which means that the last gene is exactly the objective function of this sub-problem, is 15868.2. The smaller the distance is, the better the modes are chosen, it is necessary to get the optimal combination of modes according to the comparison of the last gene values.

3	2	3	1	2	1	1	1	3	2	15868.2

Fig. 3 Encoding method of the chromosome

Based on the flow of the genetic algorithm, the obtained initial solution is to execute the crossover, mutation and selection operations. According to the fitness function, the optimal solution is selected; otherwise the operation is stopped when the termination condition is reached. The flowchart of the genetic algorithm is shown as follows:

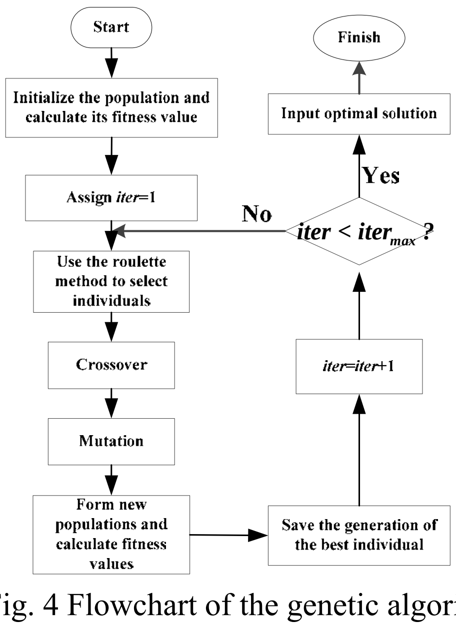

Fig. 4 Flowchart of the genetic algorithm

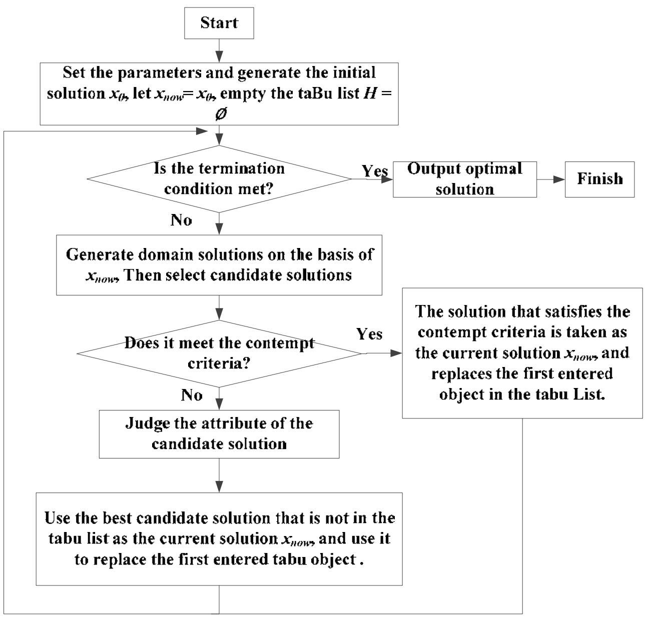

Fig. 5 Flowchart of the tabu algorithm based on dynamic logistic

After the MAP problem is solved, the mode of each task is determined, and the maintenance points that need to be traveled are also determined. The traditional RCPSP problem comes next, which is to allocate tasks and their scheduling resources. The tabu search algorithm has the characteristics of fast search speed and high efficiency and is suitable for large-scale optimization calculation. The difference from the intelligent algorithms such as genetic algorithm and simulated annealing is that the tabu search algorithm can overcome the premature phenomenon caused by local optimum. Fig. 5 shows the flow of the tabu search algorithm.

The resulting optimal solution should be a sequence of numbers, for instance, 2-3-1-4-5-7-8-6-9-10, which is the corresponding execution order of the task.

4. Experiments and Result Analysis

We run Matlab for simulation experiments in the Windows 7 system environment. The test set includes 15 non-dummy tasks, 3 modes. Here, four typical resource types are selected. The renewable resources are maintenance support personnel and equipment; non-renewable resources: energy and consumable materials. By testing the hybrid genetic tabu search algorithm in this paper, the main test indicators are the average deviation and the optimal solution ratio. The average deviation defines the average deviation between the suboptimal solution and the optimal solution after the algorithm is terminated, which is used to measure the calculation quality of the algorithm. The optimal solution ratio refers to the percentage of the optimal solution obtained by the algorithm. The stability of the algorithm can be compared according to it.

The situation on the battlefield is changing rapidly, and the maintenance environment and equipment status are dynamically changed. In the process of organizing maintenance forces to repair weapons and equipment, we need to change the logistic plan that has already been arranged.

This paper considers priority and resource constraints but adds emergency situations and the function of re-scheduling maintenance tasks in the logistic process. The implementation method is to dynamically adjust the MAP scheme of the first part, change the mode allocation, and then continue to complete the traditional RCPSP problem. For example, the mode obtained in the static logistic process is $[1,2,1,1,2,2,2,3,1,3,3,3,2,3,2,1]$. We assume that the maintenance point 2 is attacked by the enemy after the completion of the eighth task, so the subsequent equipment cannot perform the mode 2 execution anymore. Therefore, this emergency information needs to be notified to each agent, the task agent will respond to this and re-allocate the mode; the resource agent will re-arrange resources to each task under the constraint condition, and the monitor agent will execute the Gantt chart information and record reference information for the next schedule.

Table 1. Comparison of Computational Performance of the Algorithm

Problem Scale	Test indicator	HGTS	PSO	GA
15	Average Deviation (%)	0.62	1.10	1.21
	Optimal Solution Ratio(%)	88.79	74.19	73.30

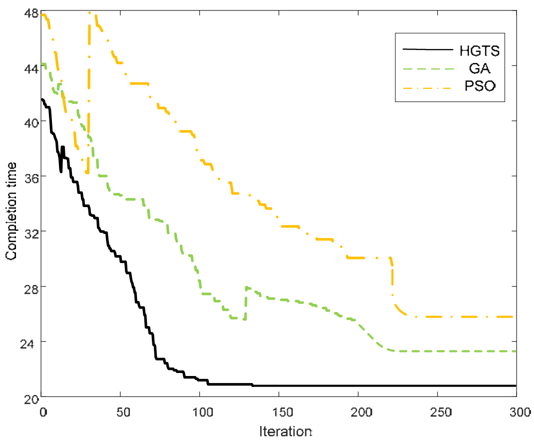

Fig. 6 The solving process of algorithm

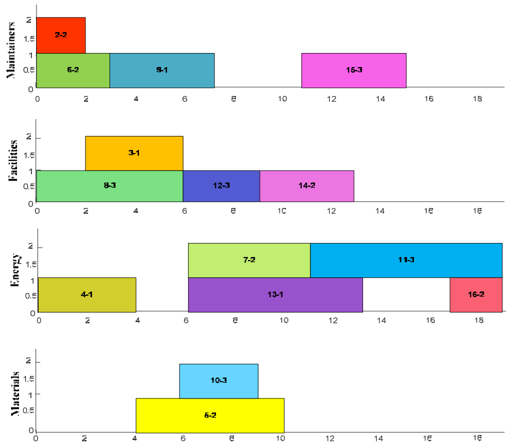

Fig. 7 The Gantt chart of the test problem

It can be seen from Fig. 6 that in solving such problems, the HGTS algorithm increases with the number of iterations, the convergence speed is faster, and the solution result is relatively more accurate than those in GA and PSO. As can be seen in Table 1, the iterative speed is relatively fast when the HGTS algorithm is selected to execute.

Therefore, in the process of importing the test table, we need to remove the mode 2 after the ninth task, and the corresponding resource availability and duration no longer exist, either. The assigned mode and the order of the tasks will change. The solution of the HGTS algorithm is $[1,2,6,3,8,4,9,5,7,10,14,11,12,13,15,16,17]$, whose mode series is $[1,2,1,1,2,2,2,3,1,3,3,3,2,3,2,1]$, and the serial scheduling generation scheme decodes the Gantt chart is shown in Fig. 7. Thus, the dynamic logistic task of the equipment support is realized.

5. Conclusion

The research of this study is dynamic logistic in the process of equipment support. Firstly, a multi agent system framework is built, including task agent, resource agent, negotiation agent, and monitoring agent. They communicate with each other and report real-time dynamics. In the dynamic logistic problem, we propose a hybrid genetic tabu search algorithm, which first decomposes the abstracted MRCPSP problem into MAP and RCPSP problems. The negotiation agent plays an important role, that is, it will notify other agents of the real-time information, so the task agent and the resource agent re-schedule the resources respectively. The modes of each task are assigned well, which means the maintenance points that all the equipment is going to are already chosen. Then the logistic problem is to solve. Comparing with the traditional genetic algorithm and particle swarm optimization algorithm, our proposed HGTS algorithm has better average deviation and optimal solution ratio, which reflects the stability and calculation quality of the algorithm. The simulation experiments have already proved the conclusion, which is of great use in the process of equipment support.

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