Advances in Intelligent Systems Research (AISR), volume 160
3rd International Conference on Modelling, Simulation and Applied Mathematics (MSAM 2018)

Model of Spare Parts Optimization Based on GA for Equipment

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***Abstract*—Combined with the engineering requirements for the optimal allocation of the current ammunition equipment spare parts, a spare part optimization model based on genetic algorithm was established. With the combination of good readiness and cost of ammunition equipment, the use of genetic algorithm had the characteristics of fast convergence, strong global optimization, and simple programming. The model was solved and the spare parts of ammunition equipment were optimally configured. Finally, an example of ammunition equipment was analyzed. The results show that the genetic algorithm can effectively solve the optimization problem of ammunition equipment spare parts.**

Keywords—equipment; genetic algorithm; spare parts optimization

I. INTRODUCTION

Optimization of spare parts is an important part of equipment support. Its goal is to seek the best balance between the readiness of equipment and the cost of support, and ultimately to determine the configuration principles of spare parts scientifically.

In recent years, many scholars at home and abroad have conducted extensive research on spare parts optimization. The literature [1-2] uses the spare part satisfaction rate as the optimization goal, and the spare part's optimization configuration model is studied with the expense as the constraint condition. The literature [3] draws on the research results of repairable parts inventory theory both at home and abroad, through the expansion of the classic METRIC model and theory, constructs a spare parts optimization model under the three-level repair supply system. The literature [4] proposes an initial spare part plan optimization method based on maximizing the marginal effect for airlines to reduce the initial spare parts cost and improve the operation demand of fleet attendance. The literature [5] proposes a non-linear planning model for optimal allocation of spare parts and proposes an optimized configuration model for electronic equipment spare parts based on a simulated plant growth algorithm. From the existing research results, most of the optimization models use a single variable as an objective function, and less consideration is proposed to the requirements for the readiness of costs and equipment.

Based on this, this paper abstracts the optimization problem of spare parts into a multi-objective optimization problem and proposes an equipment spare parts optimization model based on genetic algorithm. Under the constraint of combat readiness and cost, the model can solve the balance problem between multiple objectives. Finally, the genetic algorithm is used as the solution to get the optimal spare parts configuration of the equipment.

II. ESTABLISHMENT OF EQUIPMENT SPARE PARTS OPTIMIZATION MODEL

The primary task of equipment support is to rationally store and supply the required spare parts based on the consumption patterns of various components of the equipment. In theory, the more spare parts for equipment, the better. However, due to the limited equipment and military expenditures, it is impossible to carry out a large number of component reserves. Moreover, if the spare parts reserve exceeds the required requirements, it will result in a huge backlog of funds being unable to operate effectively and causing a lot of capital wastage. Therefore, a reasonable spare part optimization model needs to comprehensively consider the impact of equipment readiness requirements and economic factors.

A. Definition of Equipment Readiness Rate

Readiness for combat readiness refers to the ability of an equipment to begin execution of scheduled tasks at any time during normal or wartime conditions of use. The readiness of combat readiness is generally measured by the readiness rate of the project.

The consumption of equipment spare parts is considered as obeying the Poisson distribution of parameter λ_T. Where λ is the failure rate of a component and T is the duration of the operation. The equipment is composed of n basic function items. The failure rate of the i spare part is λ_i. The probability of requiring k spare parts is as follows.

$$p(k) = \frac{e^{-\lambda_i T}(\lambda_i T)^k}{k!} \tag{1}$$

Let N_{NBOi} be the postponed delivery date for the i spare part, and the inventory of the corresponding part is x_i .

$$N_{NBOi} = \sum_{k_i = x_i + 1}^{\infty} (k_i - x_i) P\{K_i = k_i\} \quad (2)$$

The availability rate of the part a_i is shown as follows.

$$a_i = \frac{N_{NBOi}}{x_i} \quad (3)$$

Therefore, the readiness rate of equipment can be expressed as follows.

$$A(x) = \prod_{i=1}^{n} (1 - a_i) = \prod_{i=1}^{n} (1 - \sum_{k_i = x_i + 1}^{\infty} (k_i - x_i) \frac{e^{-\lambda_i T} (\lambda_i T)^k}{k!}) \quad (4)$$

When the requested combat readiness rate $A(x)$ is greater than or equal to the allowable minimum value A_0, it can be considered that the equipment is equipped with the spare quantity $x = (x_1, x_2, x_3, \cdots, x_n)$ of all spare parts, which can meet the requirements of the equipment during combat.

B. Analysis of Equipment Support Costs

The support costs for equipment spare parts are generally composed of spare parts costs, ordering costs, storage costs, and out-of-stock costs. First of all, the ordering costs include the processing fee, telecommunications fee, purchase travel fee and so on. The ordering costs are related to the number of orders, but not to the order quantity. Secondly, the storage costs include interest on funds occupied by spare parts, transportation fees, and losses due to the depreciation of spare parts' performance. Storage costs are related to the quantity and storage time of spare parts. Finally, the shortage of goods refers to the loss caused when spare parts are in short supply [6]. In order to simplify the calculation model, the cost of spare parts can be expressed as follows.

$$C(x) = \sum_{i=1}^{n} c_i x_i \quad (5)$$

c_i - the cost of the i spare part;

x_i - the spare part number of the i spare part.

C. Establishment of Spare Parts Optimization Model

In the process of equipment support, the equipment readiness ratio and guarantee cost constraints are issues that must be considered. With limited funds, achieving a high rate of equipment readiness is the main goal. Under the premise of guaranteeing equipment readiness and rate constraints and cost constraints, in order to obtain the optimal configuration of spare parts, this article establishes the following spare parts optimization model for equipment.

$$\max: \frac{A(x)}{C(x)} \qquad S.t. \quad C(x) \le C_0, A(x) \ge A_0 \quad (6)$$

C_0 - the maximum allowable cost for the use of spare parts;

A_0 - the minimum allowable value for equipment readiness;

x - the matrix of spare parts.

III. SOLUTION TO OPTIMIZATION OF EQUIPMENT SPARE PARTS

Genetic algorithm was founded by Professor J.H. Holland of the University of Michigan in the 1970s. It is an adaptive probability optimization technique based on biological genetics and evolutionary mechanisms that is suitable for the optimization calculation of complex systems. The genetic algorithm takes the coding of the decision variable as the operation object, adopts the probability search technology, and directly uses the value of the objective function as the search information. At the same time, the genetic algorithm uses search information from multiple search points to ensure a globally optimized solution, and there is no a priori requirement for the mathematical model of the optimized system [7].

A. Description and Initialization of the Problem

Since the genetic algorithm cannot directly process the solution data of the solution space, it must be coded to represent the genotype string structure data of the genetic space. Chromosome encoding is commonly used. Chromosome expression is generally binary string expression, sequential expression and random bond expression. Due to the wide variety of equipment components and the upper limit of the maximum number of backups for each type of component is about 10, when using binary expressions, the strings are rather long and it is not easy to calculate. The random key uses a random number between (0,1) and does not reflect the number of backups of various components. Therefore, sequential expression is used and an ordered list of chromosomes is defined as the number of backups x_i. For example, the kth chromosome can be expressed as follows.

$$V_k = [x_{1k}, x_{2k}, x_{3k}, \cdots, x_{nk}] \quad (7)$$

The initial population of chromosomes generates a sequence of random numbers in the range [0,10], and checks the validity of each chromosome based on the readiness of equipment and cost values until it produces m legitimate chromosomes.

B. Evaluation Function

According to the spare parts optimization model, the ratio of the equipment readiness ratio to the guarantee cost is required to be the largest. At the same time, the equipment readiness ratio is greater than A_0, and the guarantee cost is less than C_0. Therefore, its evaluation function is as follows.

$$eval(V_k)=\frac{A(x)}{C(x)}=\frac{\prod_{i=1}^{n}(1-\sum_{k_i=x_i+1}^{\infty}(k_i-x_i)\frac{e^{-\lambda_i T}(\lambda_i T)^k}{k!})}{\sum_{i=1}^{n}c_i x_i} \tag{8}$$

For the legitimate chromosomes, the above formula is used for evaluation. Penalize illegal chromosomes and make them zero in fitness. Through the evaluation of the individual's fitness, the individual's degree of good or bad can be measured to determine the individual's reproductive or death.

C. Genetic Operators

The genetic algorithm determines the next generation of individuals by selecting crossover operators and mutation operators.

1) Crossover operator

Single point of intersection is used. Assume that the crossover rate P is 0.3. The chromosome used for crossover is selected using the wheel method, and the position of the breakpoint is randomly generated in [1, M]. Assume that the position is 5 and the chromosome used for the crossover is V.

$$V_1=[3\quad 1\quad 2\quad 5\quad 2\,|\,1\quad \cdots\quad 4] \tag{9}$$

$$V_2=[1\quad 2\quad 2\quad 1\quad 3\,|\,3\quad \cdots\quad 5] \tag{10}$$

The right part of the parents is exchanged with each other, and the resulting genetic offspring is shown as follows.

$$O_1=[3\quad 1\quad 2\quad 5\quad 2\quad 3\quad \cdots\quad 5] \tag{11}$$

$$O_2=[1\quad 2\quad 2\quad 1\quad 3\quad 1\quad \cdots\quad 4] \tag{12}$$

2) Mutation operator

Random camera action is used for variation. For a gene x_{ik} used for mutation, replace it with a random number of [0,10]. Assuming that the mutation rate p_m is 0.2, there are an average of mutated $M\times pop\_size\times p_m$ genes. The runner method is used to determine the gene to be mutated. For example, if the fourth gene on chromosome V_3 is selected as the variant gene, the offspring O_3 produced by the mutation is shown as follows.

$$V_3=[4\quad 3\quad 2\quad 1\quad 5\quad 6\quad \cdots\quad 4] \tag{13}$$

$$O_3=[4\quad 3\quad 2\quad 3\quad 5\quad 6\quad \cdots\quad 4] \tag{14}$$

$$O_2=[1\quad 2\quad 2\quad 1\quad 3\quad 1\quad \cdots\quad 4] \tag{15}$$

3) Selection strategy

This article uses a deterministic selection strategy. First, all the same chromosomes in the parents as the offspring are deleted. Then, the appropriate values for all individuals are analyzed. Finally, the parents and offspring are sorted according to the size of the moderate value, and the first m chromosomes are selected as the new generation population.

D. Termination Conditions

The reproductive algebra M is used as the genetic termination condition. When the reproductive generation reaches M, the inheritance is automatically terminated. After stopping the inheritance, the chromosome with the highest fitness degree is the solution sought, and the corresponding value is the spare part quantity of the equipment.

IV. CASE

Taking a certain type of equipment as an example, the equipment has four types of main spare parts. The corresponding spare unit price and failure rate are shown in Table I.

TABLE I. TABLE TYPE STYLES

Type	Unit A	Unit B	Unit C	Unit D
Cost(yuan)	5000	25000	20000	1500
λ_i (/h)	0.0005	0.00023	0.00135	0.00027

Among them, the equipment cost limit is 200,000 yuan, and the minimum combat readiness rate is 0.9. The working time T is 2000h.

The spare part optimization model of this equipment is shown as follows.

$$\max:\frac{\prod_{i=1}^{4}(1-\sum_{k_i=x_i+1}^{\infty}(k_i-x_i)\frac{e^{-T\lambda_i}(T\lambda_i)^k}{k!})}{\sum_{i=1}^{4}c_i x_i} \tag{16}$$

$$S.t.\qquad C(x)\le 200000, A(x)\ge 0.9$$

The genetic algorithm is solved by programming to solve this problem. The number of individual parts is a positive integer [1,10], the number of iterations is 150, the crossover probability is 0.3, and the mutation probability is 0.2. The optimal solution is proposed in the 78th generation. The fitness function value is 1.2305×10^{-5}, the optimal configuration $P_g=[3,2,4,3]$, the total cost of the equipment is 14,950 yuan, and the equipment readiness ratio is 0.907.

From the results, we can see that under the constraint of a given funding of 200,000 yuan, the spare parts configuration scheme of this article satisfies the requirements for the integrity of equipment readiness, and the funding is 14,950 yuan. The efficiency of the use of security costs.

V. CONCLUSION

Spare parts optimization can not only guarantee the requirements of equipment readiness, but also an important means to reduce spare parts costs. In this paper, genetic algorithm is used to solve the equipment spare parts optimization problem, and a spare parts optimization model for equipment is established. Under the constraint of cost and equipment readiness, the optimal allocation of spare parts for the best ratio of equipment readiness and cost is analyzed. The genetic algorithm is simple in algorithm, fast in convergence, requires few adjustment parameters, and has a strong global search capability. The optimal configuration of equipment spare parts. Through optimization calculation of spare parts for a certain type of equipment, it is proved that the genetic algorithm can better solve the optimization problem of equipment spare parts.

ACKNOWLEDGEMENTS

This work was supported by the Special Fund for Scientific Research of Civil Aircraft under No. MJZ-2016-F-24, the Special Fund for the Development of Science and Technology in Guangdong Province under No.2017B010116004, Guangdong Provincial Science and Technology Plan Project under NO.2017B090903006, Guangdong Provincial Science and Technology Plan Project under NO.2017A010102007, National Science and Technology Major Project of China under grant No.2016ZX04004006, 2016 Industrial Transformation and Upgrade (Made in China 2025) Key Projects in Key Projects: Promotion of Motor and Servo Drive Reliability Solutions.

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