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Optimization of University Scientific Research Project Management Resources Based on Genetic Algorithm

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Abstract. This article aims to solve the problem of resource optimization in the management of scientific research projects in universities, and proposes a resource optimization model based on Genetic algorithm (GA). By collecting and processing real data and conducting simulation experiments, this article evaluates the performance and stability of the model. The experimental results show that GA has good convergence and solution quality in resource optimization. Compared with other methods, GA has advantages in optimization effect and stability. It can maintain good performance under different data sets and parameter settings, and its stability is basically around 89.5%. The stability test further verified the reliability of the model in different scenarios. Therefore, this article holds that GA has application potential in the optimization of scientific research project management resources in universities, which can provide effective decision support for managers and realize rational allocation and efficient utilization of resources. These results provide an important reference for future research, and can promote the development of scientific research project management in universities in a more intelligent and optimized direction.

Keywords. Genetic algorithm, Scientific research projects, Management resource optimization, Allocation of resources

1. Introduction

With the country's investment in scientific research increasing year by year, as an important base of scientific research, the number and scale of scientific research projects undertaken by universities are constantly expanding [1]. This trend makes the management of scientific research projects in universities more complicated, and the types and quantity of resources involved have also increased greatly. Traditional project management methods often rely on manual experience and simple optimization model, which is inadequate in the face of large-scale and multi-objective optimization problems [2]. In addition, the management of scientific research projects in universities involves a variety of resources such as manpower, material resources and financial resources, and the distribution and deployment of these resources directly affects the progress and quality of scientific research [3]. If the allocation of resources is unreasonable, it may not only lead to excess resources and waste in some projects, but also delay other projects due to resource shortage [4]. In this case, how to manage scientific research project

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resources reasonably and efficiently has become an important issue [5]. Therefore, it is needed to introduce more advanced optimization algorithms to improve the efficiency of resource management.

GA is an optimization algorithm that simulates natural selection and genetic mechanism [6]. Its basic principle is to simulate the mechanism of natural selection, heredity, crossover and mutation in the process of biological evolution, and find the optimal solution or near optimal solution of the problem through continuous evolution from generation to generation [7]. GA possesses global search capability and implicit parallelism, rendering it effective in tackling complex problems that are often challenging for traditional optimization methods. This is particularly true for large-scale, nonlinear, and multi-peak optimization problems [8]. Consequently, GA has found widespread applications in diverse fields, including function optimization, combinatorial optimization, machine learning, production scheduling, and more. By integrating GA into the optimization of scientific research project management resources in universities, we can enhance the rationality of resource allocation, reduce management costs, and facilitate the smooth progression of scientific research projects.

The research backdrop of this article is rooted in the requirement for resource optimization in scientific research project management in universities and the extensive utilization of GA in the realm of resource optimization. The significance of this research lies in augmenting the efficiency and rationality of scientific research project management resource optimization in universities through the application of GA. It also aims to provide decision-making support for scientific research project management in universities. Furthermore, the introduction of GA, an advanced optimization method, into scientific research project management in universities represents an innovation and improvement of traditional management methodologies. This advancement is conducive to propelling the progress of project management as a discipline.

2. Optimization Theory and GA of Scientific Research Project Management Resources in Universities

The management of scientific research projects in universities is a complex and critical process, which involves all stages from project application, project establishment, implementation to conclusion. In this process, universities need to ensure that scientific research projects are carried out in accordance with the established time, cost and quality objectives [9]. Efficient and scientific project management methods can ensure the rational use of resources, improve scientific research output and promote scientific and technological progress. The management of scientific research projects in universities involves many stakeholders, including project team members, management departments and funding institutions. To ensure the smooth progress of the project, it is needed to effectively manage and allocate human resources, material resources and financial resources.

The theory of resource optimization is a theory that studies how to achieve specific goals through scientific allocation and planning under limited resources [10]. In the management of scientific research projects in universities, resource optimization means more reasonable and efficient use of human, material and financial resources to ensure the smooth progress and high-quality completion of scientific research projects. The core of resource optimization theory is to minimize resource consumption and waste on the premise of meeting project requirements. This involves a series of methods and techniques, such as linear programming, dynamic programming, integer programming and so on [11]. These methods and technologies can provide decision support for the management of scientific research projects in universities and realize the maximum utilization of resources.

GA is an optimization method that draws inspiration from the principles of biological evolution. It mimics the natural selection and genetic mechanisms to locate the most optimal solution within a given search space. In GA, the solution to the problem is encoded as a “chromosome”–a sequence of either numerical or binary codes. To begin, a set of chromosomes is generated randomly to serve as the initial population [12]. Subsequently, everyone in the population is assessed according to the fitness function, and those with higher fitness values have increased likelihoods of being chosen for genetic operations. These genetic operations comprise of selection, crossover, and mutation. The selection operation entails picking outstanding individuals based on their fitness, the crossover operation involves randomly choosing two individuals to swap certain genes, and the mutation operation implies randomly altering some genes of an individual. Through these operations, GA optimizes the solutions iteratively. Through several rounds of genetic operation, individuals in the population gradually adapt to the problem, and finally the optimal individuals in the population are the approximate optimal solutions of the problem.

3. Optimization Model of Scientific Research Project Management Resources in Universities Based on GA

In resource management, GA can be used to solve complex resource optimization problems. It can deal with multiple objectives and constraints, and can quickly find approximate optimal solutions in large-scale problems. Compared with traditional optimization methods, GA has stronger global search ability and higher efficiency. In the management of scientific research projects in universities, GA can be used for the allocation and scheduling of resources. GA can be used to determine the proportion of resource allocation among various projects, to maximize the overall benefit of resource utilization. In addition, GA can also be used for project scheduling to determine the priority and execution order of projects, so as to minimize project delay and waste of resources. To construct a resource optimization model for scientific research project management in universities based on GA, it is essential to first clarify the objective of the model. Specifically, the goal is to achieve optimal allocation of scientific research project resources in universities, enhance the efficiency of resource utilization, and reduce management costs. Figure 1 illustrates the optimal allocation management of scientific research project resources in universities.

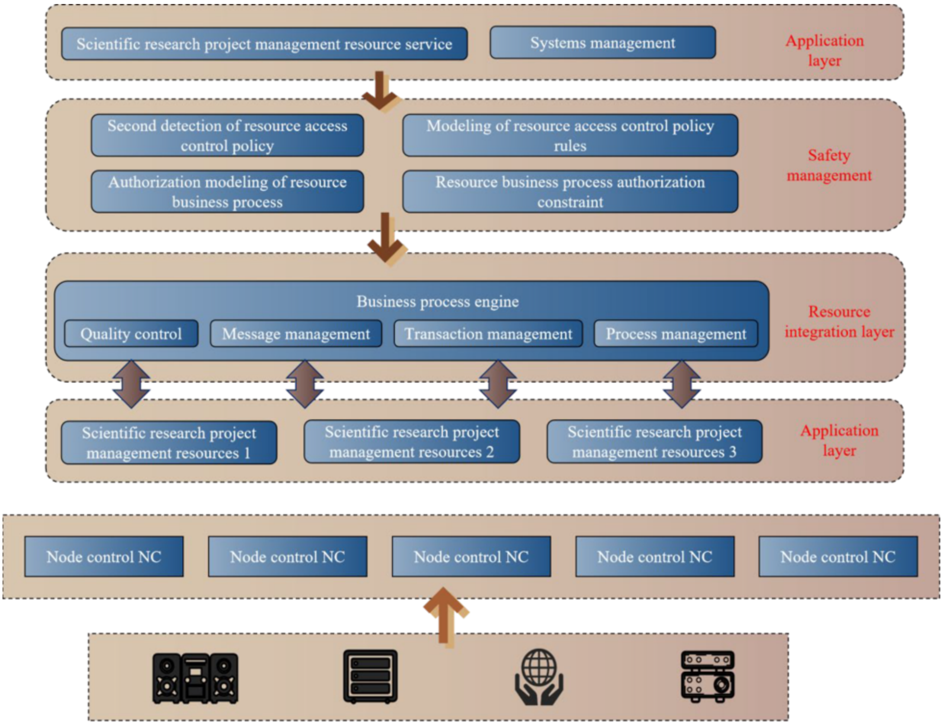

Figure 1. Optimal allocation and management of scientific research project management resources in universities.

The idea and steps of the model construction in this article are as follows: Defining the optimization goal: The core of scientific research project management in universities is how to allocate and utilize resources reasonably and effectively. Therefore, the optimization goal can be set to minimize the resource cost. This means that under the premise of meeting the needs of scientific research projects, we hope to use as few resources as possible to complete these projects. In addition, in order to make a more comprehensive consideration, other optimization objectives can also be introduced, such as maximizing the efficiency of resource utilization and ensuring the balanced and efficient utilization of resources among various projects.

Determine decision variables: In the resource optimization model, the choice of decision variables is very important. For the management of scientific research projects in universities, the decision variables can be set as the resource allocation and project priority of each project. The resource allocation determines the number of resources that each project can get, while the project priority determines which projects should get resources first when resources are limited.

Design constraints: to ensure that the optimization results are consistent with the actual situation, various constraints need to be considered. First, the limitation of total resources is an important constraint, which ensures that the allocated resources do not exceed the total resources owned by schools or institutions. Secondly, the resource demand of each project is also one of the constraints, ensuring that each project obtains at least the minimum number of resources it needs. Finally, this article comprehensively considers the constraints of time, technology and manpower to ensure that the optimization scheme is feasible in practical operation.

Choosing the appropriate GA and encoding method: The selection and encoding method of GA is closely related to the nature of the problem. For the optimization of scientific research project management resources in universities, binary or real coding can be used. Binary coding is simple and intuitive, while real coding can provide higher accuracy and flexibility. Which encoding method to choose depends on the specific needs and complexity of the problem. In this article, the GA utilizes floating-point number coding, and the crossover operator employs non-uniform linear crossover, as depicted by the formula below:

$$\begin{cases} x_1^{'} = r_1 x_1 + \left(1 - r_1 x_2\right) \\ x_2^{'} = r_2 x_2 + \left(1 - r_2 x_1\right) \end{cases} \tag{1}$$

Among them, $r_1 \in (0,1), r_2 \in (0,1)$ are randomly generated.

Design of fitness function: Because the optimization goal of this article is to minimize the resource cost, the fitness function can be designed as the reciprocal of the resource cost. This design can ensure that GA is more inclined to choose those solutions with lower resource cost in the search process. At the same time, to meet the needs of multi-objective optimization, this article extends or weights the fitness function. The fitness function value is used to evaluate the advantages and disadvantages of each solution, and this article takes it as:

$$f = \frac{\sqrt[a]{n}}{\sum_{i \neq j} d_{ij} x_{ij}} \tag{2}$$

Where a is a preset constant, n is the number of resources, and $\sum_{i \neq j} d_{ij} x_{ij}$ is to minimize the resource cost. For a given population of size n:

$$P = \{a_1, a_2, \cdots, a_n\} \tag{3}$$

The fitness value of individual a_j is $f\left(a_j\right)$, and its selection probability is:

$$p\left(a_j\right) = \frac{f\left(a_j\right)}{\sum_{i=1}^{n} f\left(a_i\right)}, \qquad j = 1, 2, \cdots, n \tag{4}$$

Detailed explanation of genetic operation: selection operation: selection based on fitness is one of the core steps of GA. Crossover operation: crossover is the main way to generate new individuals in GA. By randomly selecting some genes of two parents and exchanging them, two new offspring individuals are produced. Crossover operation can combine the advantages of parents and help accelerate the convergence speed of the algorithm. By randomly changing some genes of some individuals, the diversity of the population can be increased, and the algorithm can be explored more widely in the search space. Let $s_{\max}$ be the fitness value of the optimal sequence in this generation, $\overline{s}$ be the average fitness value of the sequence, and s be the fitness value of a sequence, then the crossover probability P_c and mutation probability P_m of this sequence are defined as:

$$P_c = \begin{cases} \dfrac{k_1\left(s_{\max} - s\right)}{s_{\max} - \overline{s}}, & s \geq \overline{s} \\ k_3, & s < \overline{s} \end{cases} \tag{5}$$

$$P_m = \begin{cases} \dfrac{k_2\left(s_{\max} - s\right)}{s_{\max} - \overline{s}}, & s \geq \overline{s} \\ k_4, & s < \overline{s} \end{cases} \tag{6}$$

$$k_1, k_2, k_3, k_4 \leq 1 \tag{7}$$

This article adopts adaptive method to adjust the crossover probability:

$$P_c = \frac{1}{2 + 0.8\ln G} + \varphi \tag{8}$$

Where G is an evolutionary algebra; φ is the convergence limit of crossover probability. Its changing trend is shown in Figure 2.

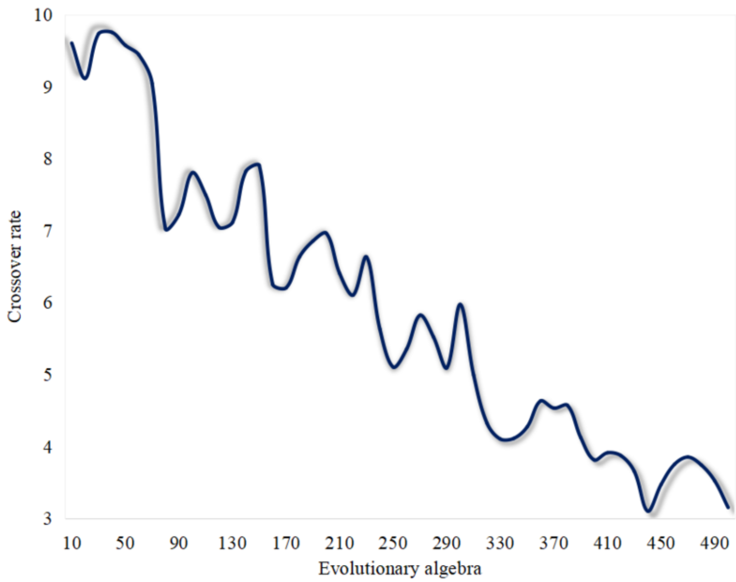

Figure 2. GA crossover rate adaptive schematic diagram.

The purpose of using GA is to find the optimal fuzzy membership function parameters a_{ij}, σ_{ij}, so that:

$$\min E = \frac{1}{2}\sum_{i=1}^{n}\left(u-u_i\right)^2 \tag{9}$$

Where u is the expected output and u_i is the model output value. The learning goal is to minimize E.

By defining optimization objectives, determining decision variables, designing constraints, selecting appropriate GA and coding methods, and formulating adaptive genetic operations, a complete optimization model of scientific research project management resources in universities can be constructed. This model will provide scientific decision-making basis for the management of scientific research projects in universities, and promote the rational distribution and efficient utilization of resources.

4. Model Simulation Evaluation and Performance Comparison

To verify the validity and performance of the model, it is needed to adopt appropriate methods to verify it. In this article, GA-based optimization model is compared with other traditional resource management methods to compare their performance in optimization effect and computational efficiency. Before the simulation experiment, data collection and processing are needed first. The sources of data include the management records of historical research projects in universities, data collected based on surveys and questionnaires. The main contents of data collection include the resource demand, project priority, project completion time and resource cost of each project. These data will be used to construct the input parameters and constraints of the resource optimization model. In the data processing stage, data need to be cleaned, sorted and normalized. The purpose of data cleaning is to remove outliers and noise data and ensure the quality of data. Data collation is to collate and format the collected original data for subsequent modeling and simulation. Normalization operation is to map the data to a unified scale and eliminate the dimensional influence between different data.

Firstly, whether the model can find a scheme close to the optimal solution in a limited time is evaluated. For GA, the convergence speed is an important index, which determines the efficiency of the algorithm in practical application. The experiment set the population size as 100, the crossover probability as 0.8 and the mutation probability as 0.1. The maximum number of iterations is set to 500 generations. Besides GA, even distribution method and priority method are also implemented as control experiments. Figure 3 shows the details of the convergence speed of the model.

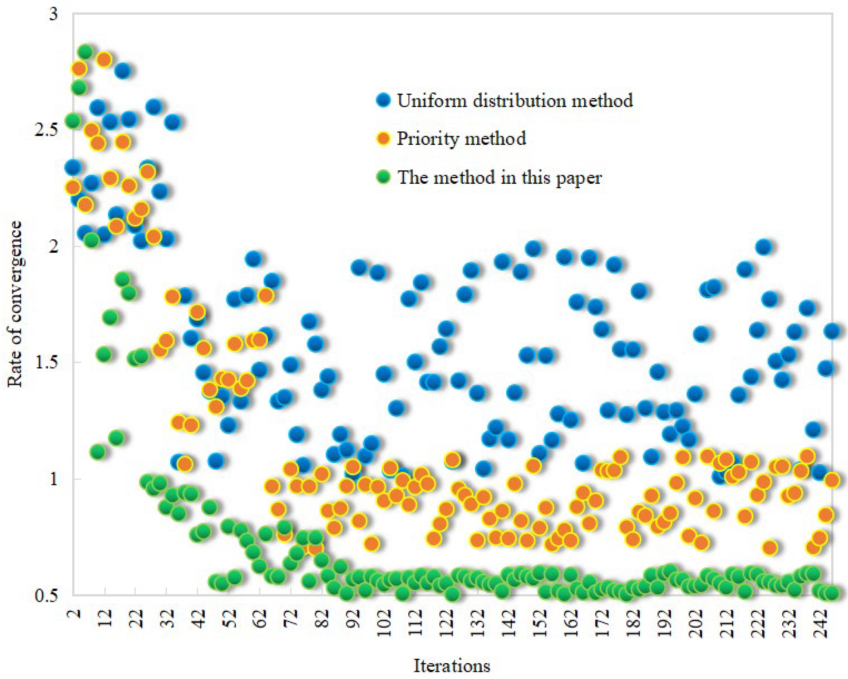

Figure 3. Convergence rate of model.

As shown in Figure 3, we can observe the convergence speed of GA in resource optimization. At the beginning of the algorithm, because the individuals in the population are randomly generated, the fitness value distribution is scattered. However, with the iteration, the fitness gradually concentrates and tends to be optimized. In the middle stage, GA began to explore more solution spaces through crossover and mutation operations. At this point, the convergence speed is obviously accelerated, which reflects the global search ability of GA. In the later period, with the increase of iteration times, the individuals in the population gradually converge and the convergence speed slows down. However, due to the fine-tuning ability of GA, a better solution can still be found in the later stage. Compared with other methods, the uniform distribution method has a stable but slow decline rate in the whole process, while the priority law has a faster decline rate in the initial stage, but it is easy to fall into local optimum in the later stage.

Secondly, this section has carried on the stability test. Evaluate the performance changes of the model under different data sets or parameter settings. A good model should be stable, that is, it can maintain good performance in different scenarios. This article selects three data sets of scientific research projects in universities with different scales and data distribution. Data set A contains 50 items, data set B contains 100 items, and data set C contains 150 items. Each data set contains information such as resource requirements and priorities of the project. For GA, the key parameters such as population size, crossover probability and mutation probability are adjusted on each data set to observe the influence of parameter changes on the stability of the model. At the same time, the uniform distribution method and priority method are also applied to each data set to compare the stability with GA. The stability of different models under different data sets is shown in Figure 4, Figure 5 and Figure 6.

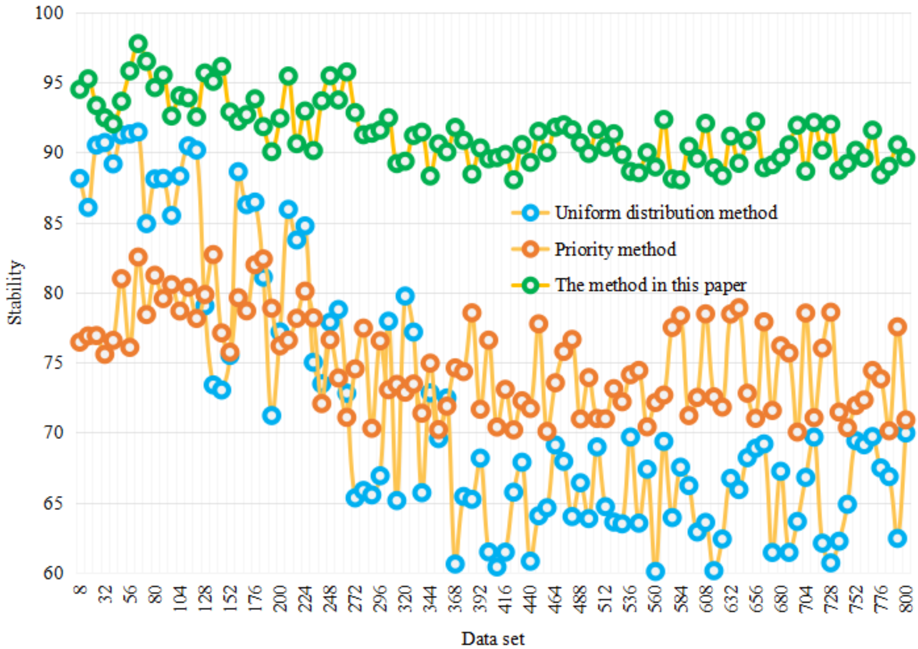

Figure 4. Stability of different models in data set A.

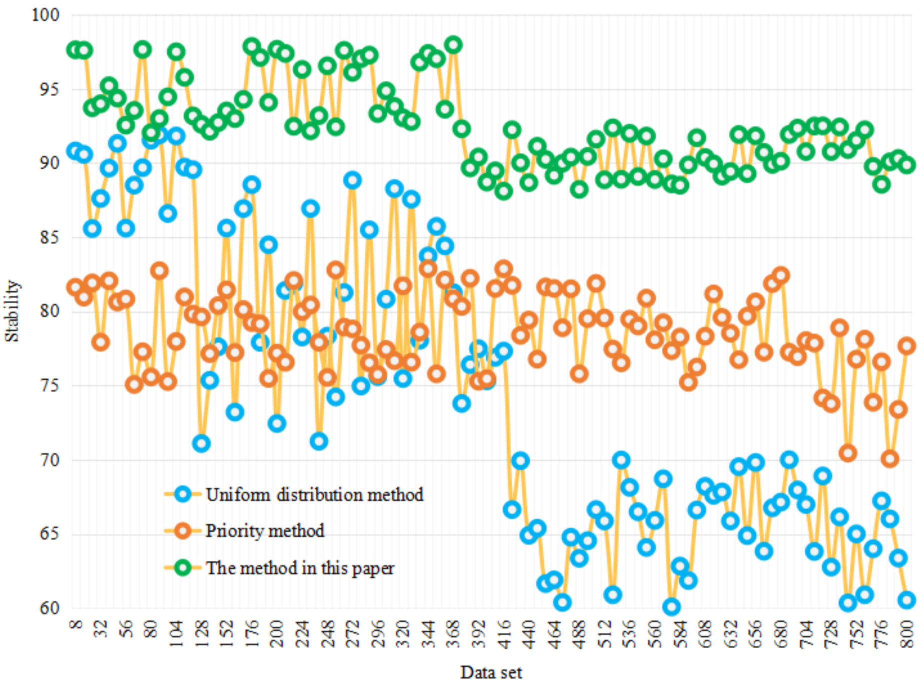

Figure 5. Stability of different models in data set B.

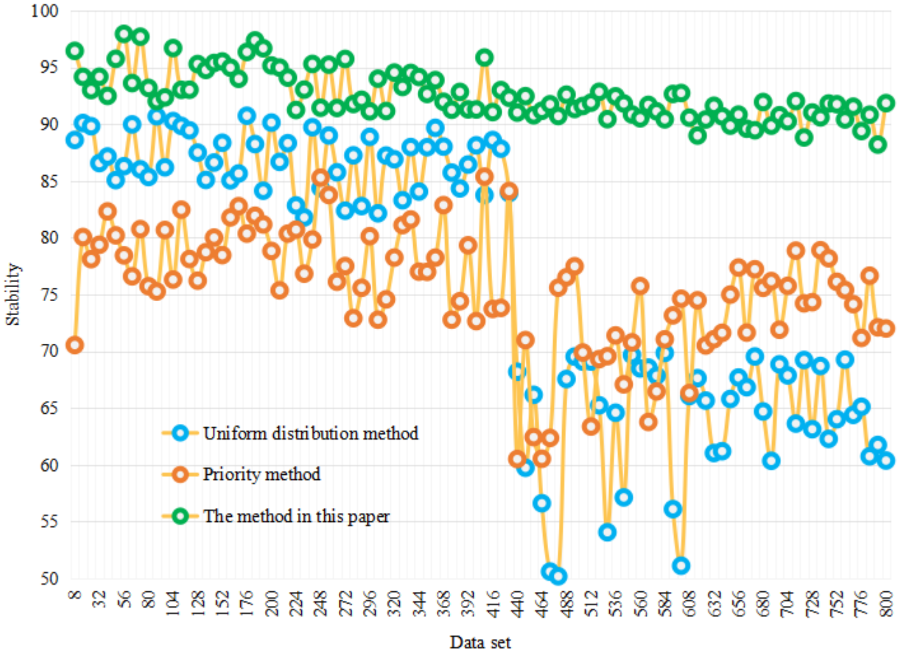

Figure 6. Stability of different models in data set C.

As shown in the above figure, GA shows good stability on three data sets with different scales. With the increase of data set size, the performance of GA declined slightly, but the overall trend was stable, which was about 89.5%, and there was no significant fluctuation. This shows that GA has good adaptability to the data sets of scientific research projects of different scales. However, the even distribution method and priority method are not as good as GA in stability. Especially when the size of data sets increases, their performance declines more obviously. This shows that the traditional method is not as stable as GA in the face of complex and changeable data sets.

Through the test of convergence speed and stability of the model, this section verifies the advantages of GA in the optimization model of scientific research project management resources in universities. This provides strong support for the wide application and reliability of the model.

5. Conclusions

Through the research of this article, aiming at the resource optimization problem of scientific research project management in universities, an optimization model based on GA is put forward, and detailed experimental verification and performance analysis are carried out. GA can achieve global optimization under large-scale and multi-constraint conditions, which is helpful to improve the overall utilization efficiency of resources. Through experiments, we can clearly see the advantages of GA in convergence speed. This reflects the efficiency and effectiveness of GA in solving the problem of optimizing the management resources of scientific research projects in universities. At the same time, GA has advantages in stability. It can maintain relatively stable performance on data sets of different scales and distributions, which is very important for practical applications in the face of various scenarios and data changes. In addition, the control experiment also verified the advantages of GA over other traditional methods. It provides an effective method and tool for the management of scientific research projects in universities. However, although GA has shown good performance in resource optimization of scientific research project management in universities, there are still many directions worthy of discussion and research. In this study, the constraints of total resources and project requirements are mainly considered. However, in practice, there may be other constraints, such as time window constraints, technical feasibility constraints and so on. In the future, it will be more helpful to improve the practicability and accuracy of the model by incorporating these constraints into the optimization model and studying the corresponding GA.

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