International Journal of Innovative Computing, Information and Control
Volume 16, Number 5, October 2020
ICIC International ©2020 ISSN 1349-4198
pp. 1667–1680

# MULTI-RESOURCE EQUILIBRIUM OPTIMIZATION OF SCIENTIFIC RESEARCH PROJECTS BASED ON PIGEON COLONY ALGORITHM

Qingfeng Meng[1,2] and Meng Zhang[3]

[1]School of Technology
Tarim University
No. 1487, East Tarim Avenue, Xinjiang 843300, P. R. China
mengqf@nsfc.gov.cn

[2]National Natural Science Foundation of China
No. 83, Shuangqing Road, Beijing 100085, P. R. China

[3]School of Cyber Science and Engineering
Xi'an Jiaotong University
No. 28, Xianning West Road, Xi'an 710049, P. R. China
mengzhang2009@xjtu.edu.cn

Received January 2020; revised May 2020

Abstract. *Balanced use of multiple resources has a significant impact on the quality of scientific research projects. Resources can be balanced by rationally arranging the implementation time of each project task. Traditional optimization problem solutions such as 'fixed project cycle and resource balance' include intelligent optimization algorithms such as genetic algorithms and particle swarm optimization. However, this paper innovatively applies the pigeon population algorithm to balancing and optimizing the use of multiple resources in scientific research projects. Firstly, the three aspects of cost, time difference and work importance are considered in order to establish a comprehensive evaluation system based on resource importance. A multi-resource equilibrium optimization mathematical model is then proposed in order to minimize the resource use variance. Finally, an example is tested to verify the effectiveness of the algorithm. Experiments show that the pigeon colony algorithm can effectively solve the optimal solution of multi-resource equilibrium optimization in scientific research. The work plan arrangement provided is more balanced than the initial solution and the suboptimal result chosen by project managers. Therefore, the pigeon colony algorithm has wide application prospects for scientific research projects and will have wide application prospects.*
**Keywords:** Pigeon colony algorithm, Resource importance evaluation, Multi-resource balanced optimization, Research project management

1. **Introduction.** With the rapid development of social economics, science and technology, the implementation of scientific research projects has become more complicated and large-scale, and the use of scientific research resources is more demanding. In the past, only quantity needs to be met, but research now requires the balanced use of resources to reduce scientific research funding and motivate scientific researchers. Therefore, scientific research project managers seek methods to reduce resource demand fluctuations, eliminate the phenomenon of peaks and troughs, and realize equalization of resource. To address the problem of resource allocation and ensure optimal allocation of the fixed project duration and resource balance, the common solution is to reasonably adjust the implementation time of various tasks in the project to balance the use of resources [1].

DOI: 10.24507/ijicic.16.05.1667

In recent years, intelligent algorithms have been widely used in different research fields such as combinatorial optimization, robotics, and computers due to their versatility, efficient search execution, easy implementation, independent of actual models, and optimization of large-scale complex problems [2]. Therefore, the optimal allocation of scientific research project resources is often completed by intelligent algorithms. Huang et al. used genetic algorithms to solve mathematical optimization models. By reasonably arranging the start time of activities on non-critical paths and adjusting the order of resource use in different activities, the peak of the resource curve was reduced as much as possible, so that resource consumption was in the state of equilibrium [3]. Şahin and Kellegöz combined integer linear programming formula with particle swarm algorithm to solve the problem of resource input and balance of multi-person workstations [4]. Myszkowski et al. linked traditional classic heuristic priority rules with ant colony optimization algorithms to make the search process faster and more stable [5]. The above-mentioned intelligent algorithms are to simulate the process of material change in nature, biological activities and evolution. Genetic algorithm is a search method based on the principles of natural selection and genetic inheritance. It is not restricted by the search space, and does not need the continuity and differentiability of optimization function. It also has parallelism, which is more suitable for resource equilibrium optimization problems with complex constraints. The particle swarm algorithm is based on the cooperation of individuals. At the same time it uses the ideas of biological self-learning and social learning to complete the search for the optimal solution. The algorithm is very simple to implement, and it has good globality and locality. The ant colony algorithm realizes path search through the information exchange and cooperation of ants. It has dynamic characteristics and is more suitable for the variability of dangerous environment. Intelligent algorithms such as genetic algorithms and ant colony algorithms with random characteristics generally have good globality and locality, they can overcome the limitations of deterministic algorithms to generate multiple solutions, but they have a large number of calculations and slow convergence. It is difficult to meet the actual needs of the projects.

In order to overcome the shortcomings of the above algorithms, some new natural heuristic algorithms are constantly being proposed, such as the new intelligent bionic optimization algorithm proposed by Li and Duan. The algorithm has the advantages of fewer parameters, convenient debugging, fast convergence speed, and good robustness and is widely used in optimization problems [6]. In addition, there are very few cases of applying pigeon group algorithm to optimizing resource balance. We try to use it in resource balance optimization to provide a basis for future research and improvement. Therefore, this article attempts to use the pigeon colony algorithm to optimize the project resources in a balanced way. Through Matlab programming and the combination of experimental data to verify the algorithm optimization effect, it is found that the pigeon colony algorithm can make a good arrangement for scientific research projects with high engineering value.

The rest of the paper is organized as follows. Section 2 expounds the basic theory of multi-resource balanced optimization of scientific research projects. Section 3 presents the mathematical model of the pigeon population algorithm. Section 4 develops multi-resource equilibrium optimization model for scientific research projects. Section 5 provides experimental results and corresponding optimization effect analysis of the proposed scheme. In the end, Section 6 concludes the paper.

2. **Basic Theory of Multi-Resource Equilibrium Optimization of Scientific Research Projects.** The completion of any scientific research project requires a certain

amount of resources. Resources used in scientific research projects may include experimental equipment, researchers, sites and network resources, etc. Resources are the key to ensure smooth and effective implementation of a project and are important factors related to the quality of project completion and the use of funds. The core issue that must be considered by every research project manager is how to skillfully use resources in a project in order to achieve smooth implementation of the project while improving quality and minimizing costs [7-10].

In general, many scientific researchers are required to complete scientific research projects. Each scientific researcher needs to complete their tasks on time under the arrangement of the leader. During the process, they may require use of common experimental equipment resources. Management of use of these resources among multiple researchers in order to achieve projects on time and with high quality is a complex and meaningful issue. The traditional method of managing resources is to sort the implementation time of each task to ensure that the time distribution of resources meets the optimization goal. Depending on the actual project situation, resource optimization issues can be mainly divided into the following two categories.

1) Fixed cycle and balanced resource: For constant cycles, the planning arrangement should be adjusted to balance the resource demands as much as possible.

2) Shortest cycle and limited resource: Where there are resource constraints, the planning should be optimized to make the construction period as short as possible.

The problem of resource equalization refers to the first type of problem. An imbalance of resources can occur in scientific research projects and peaks and troughs can often appear in resource demand curves. The main reason for this imbalance is that non-critical work is not arranged reasonably at the start, leading to a short-term situation where there is an excessive concentration of resource demands. The purpose of resource balance optimization is to make full use of the available time for non-critical work without changing the cycle of scientific research projects. This can be achieved by changing the start time of non-critical work tasks in order to transfer it from peak periods of resource demands and arrange for it to be completed during low-demand time periods. By cutting peaks and filling valleys, the fluctuation of resource requirements can be minimized as much as possible [11-14].

## 3. Mathematical Model of the Pigeon Population Algorithm.

**3.1. Pigeon algorithm.** Pigeons have a strong homing nature and have a deep memory of environments they have lived in. Regardless of how far pigeons fly, they can rely on their own powerful navigation capabilities to fly back exactly to their starting point, at any time under various environmental conditions. In 2014, Professor Duan Haibin combined biobionics and computer science and innovatively proposed the Pigeon-Inspired Optimization (PIO) algorithm through in-depth research into the homing habits of pigeons.

During flight, pigeons will use different cruising tools depending on different situations. When a pigeon is far away from its destination, it will use the geomagnetic field to identify its direction, and when it is closer to the destination, it will use local landmarks for navigation. The effects of the sun, the geomagnetic field, and landmarks, as well as the Map & Compass and Landmark operators, are introduced below.

**3.2. Map & Compass operator.** Pigeons can use magnetic objects to sense the magnetic field, then build a map in their brain, and use the sun's height as a compass to adjust their flight direction in real time.

For the flock optimization model, virtual pigeons are used for simulated navigation. Each individual in the pigeon group corresponds to a feasible solution of the model, with its own position $x_i$ and speed $v_i$ that are shown by (1) and (2), respectively:

$$x_i = [x_{i1}, x_{i2}, x_{i3}, \ldots, x_{id}] \tag{1}$$

$$v_i = [v_{i1}, v_{i2}, v_{i3}, \ldots, v_{id}] \tag{2}$$

where $i = 1, 2, 3, \ldots, N_p$ is the number of pigeons and $d$ is the dimension of the solution.

The algorithm uses iteration to simulate the continuous flight of the pigeons towards their target location. At each update iteration, each individual's position $x_i$ and velocity $v_i$ in the flock will be updated in $d$-dimensional space. The specific update principles are shown in (3) and (4):

$$v_i(t) = v_i(t-1) \times e^{-Rt} + rand \times (x_g - x_i(t-1)) \tag{3}$$

$$x_i(t) = x_i(t-1) + v_i(t) \tag{4}$$

where $t$ is the current number of iterations, $R$ is the Map & Compass factor, which is generally taken as a decimal within the range [0 1], $rand$ is a random number with a value within the range [0 1], and $x_g$ is the global maximum in the pigeon population after $t-1$ iterations. The optimal individual position of each pigeon can be obtained by comparing the fitness function values of all pigeon positions.

After completing a specified number of iterations, the Map & Compass operator will exit the loop and no longer operate, and the last obtained pigeon group position $x_i$ will be passed to the next Landmark operator to continue the iterative operations.

3.3. **Landmark operator.** For the Landmark operator iterations, individuals in the herd are firstly sorted in descending order of fitness value and the better half selected and the poorer half discarded. As the number of pigeons changes, the current center position of the remaining pigeons is calculated using (6) as the new reference direction, and the individual position $x_i(t)$ of each pigeon is updated using (7).

$$N_p = \frac{N_p(t-1)}{2} \tag{5}$$

$$x_c(t) = \frac{\sum_{i=1}^{N_p} x_i(t) \times \mathit{fitness}(x_i(t))}{N_p(t) \times \sum_{i=1}^{N_p} \mathit{fitness}(x_i(t))} \tag{6}$$

$$x_i(t) = x_i(t-1) + rand(x_c(t) - x_i(t-1)) \tag{7}$$

The function $\mathit{fitness}(x_i(t))$ is an adaptive function, and can be divided depending on the value of the solution required by the model objective function as follows:

$$\mathit{fitness}(x_i(t)) = \begin{cases} F(x_i(t)) \\ 1/(F(x_i(t)) + \varepsilon) \end{cases} \tag{8}$$

Among them, $F(x)$ is the objective function of the model, when the maximum value of the objective function is solved, the adaptive function is $\mathit{fitness}(x_i(t)) = F(x_i(t))$, and when the minimum value is solved, the adaptive function is $\mathit{fitness}(x_i(t)) = 1/(F(x_i(t)) + \varepsilon)$, where $\varepsilon$ is a finite amount close to zero.

Similarly, after a specified number of iterations, the Landmark operator will stop working, and the pigeons will fly to their destination. Finally, individual $x_i(t)$ that is the nearest to the destination will be identified as the optimal solution sought by the model objective function.

3.4. **Steps of the pigeon breed algorithm in multi-resource equilibrium optimization.** Before executing the algorithm program, the relevant parameters of the pigeon colony algorithm must be initialized. These parameters are the number of pigeon colonies $N_p$, the dimension of the solution space $d$, the Map & Compass factor $R$, the maximum number of Map & Compass iterations $T_1$ and the maximum number of Landmark operator iterations $T_2$. The upper and lower boundary bound of the space should be solved to generate the initial population. Additionally, throughout the entire execution of the algorithm, each individual in the pigeon flock must satisfy the constraint condition of (14). At each iteration, the rationality of each individual in the population is checked. Any individual that does not meet the constraints, with the exception of the optimal value $x_g$, is not acceptable and that individual's position must be re-initialized. After the Map & Compass operator has been iterated a maximum number of times $T_1$, the Landmark operator iterations are performed. When the number of iterations is greater than $T_2$, the optimal solution $x_g$ that is output will provide the scientific project work arrangement plan with the smallest multivariate variance.

The implementation steps of the pigeon colony algorithm are shown in flow Table 1.

## 4. Multi-Resource Equilibrium Optimization Model for Scientific Research Projects.

4.1. **Resource equalization objective function.** Commonly used indicators for evaluating resource balance include variance, imbalance coefficient, range, and maximum absolute deviation. The variance is an important indicator of the degree of dispersion in statistics. The smaller the variance value, the higher the equilibrium of resources. This paper chooses the most widely used variance in the engineering practice as the objective function.

The single resource equilibrium optimization problem can be understood as optimization of a resource's balance, i.e., a single objective optimization problem [15-21]. For $m$ resources, the resource equilibrium optimization will have $m$ objective functions. In actual scientific research activities, the goal of achieving optimal equilibrium of various resources is often conflicting. If one resource is in the optimal equilibrium state, another resource may be in extremely imbalanced status. Therefore, in order to take account of the multiple goals of the equilibrium of various resources, and achieve the overall balance of multiple resources, the traditional weighted summation method is used to assign a weight coefficient to each objective function to transform the multi-objective optimization into a single-objective optimization problem in this paper. The transformed objective function is

$$\min \delta^2 = \sum_{s=1}^{m} w_s \delta_s^2 \tag{9}$$

where $\delta_s^2$ is the variance of the resource.

4.2. **Comprehensive evaluation system of resource importance.** In actual scientific research projects, multiple resources may be consumed and different resources will not have the same contribution $w_s$ to the equalization goal. The weight of each resource in the objective function can be obtained based on a previous study [3] combined with the actual establishment of a resource importance evaluation index system. There are three main evaluation indicators: work importance index, importance index of total jet lag and cost importance index.

1) Work importance index

Table 1. Algorithm framework

```
Algorithm 1. Pigeon Algorithm
  Input: Set parameters in the algorithm: N_p, d, R, T_1, T_2
  Output: The best individuals: x_g
  Set the position x_i and velocity v_i of individuals in pigeons, remove individuals that
do not meet the constraints
  Find the best individual x_g in the current pigeons
  function 1 (Map & Compass operations)
        for t = 1 to T_1 do
              for i = 1 to N_p do
                    Update x_i and v_i according to (3) and (4)
                    Calculate δ^2(x_i) and find x_g in pigeons
                    if x_g meet the s.t. then
                      Update x_g
                    else
                      Adopt last x_g and Re-update x_i & v_i of this individual
                    end if
              end for
        end for
  end function 1
  function 2 (Landmark operations)
        for t = 1 to T_1 + T_2 do
              Rank the individuals in pigeons according to their fitness value
              Keep the better half and discard the other, so N_p(t) = N_p(t − 1)/2
              Calculate x_c in new pigeons according to (6)
              for i = 1 to N_p do
                    Update x_i according to (7) and find x_g in pigeons
              end for
              if x_g meet the s.t. then
                    Update x_g
              else
                    Adopt last x_g and Re-update x_i & v_i of this individual
              end if
        end for
  end function 2
```

If all the work in the project requires some kind of resource, the importance of this kind of resource is high; on the contrary, if only a little work occupies some kind of resource, this kind of resource is of low importance. The importance index of work refers to the proportion of the number of jobs requiring certain resources to the total number of scientific research projects. The work importance indicator for resource $s$ can be expressed as:

$$P_s = \frac{P(Q_s)}{\sum_{s=1}^{m} P(Q_s)} \tag{10}$$

where $Q_s$ is the total demand for resource $s$ for a scientific research project and $P(Q_s)$ is the number of jobs requiring resource $s$ in the project.

2) Importance index of total jet lag

Jet lag is the maneuvering time present at work or on the line. The greater the total jet lag of the work, the longer time it takes to use resources, and the resource equilibrium is more likely to be realized. The total jet lag importance index refers to the proportion of the sum of the total time difference of the work requiring a certain resource compared to the sum of the time difference of the work requiring all resources. The total time difference importance of resources indicator can be expressed as:

$$T_s = \frac{T(Q_s)}{\sum_{s=1}^{m} T(Q_s)} \tag{11}$$

where $T(Q_s)$ is the sum of the total time difference of all work occupying resources $s$ in the project.

3) Cost importance index

In actual scientific research projects, the ultimate goal of balanced resource optimization is to reduce project costs, so it is necessary to use cost as an indicator of resource importance. The cost importance indicator refers to the proportion of the cost of a certain resource compared to the cost of all resources. For example, if a project has a total of $N$ tasks and a total of $m$ resources are required, the cost importance indicator of the resources can be expressed as:

$$C_s = \frac{C(Q_s)}{\sum_{s=1}^{m} C(Q_s)} \tag{12}$$

where $C(Q_s)$ is the cost function of resource $s$ in the project.

A weighted sum of the three indicators, i.e., the resource importance evaluation indicator system-cost importance indicator $C_s$, the work importance indicator $P_s$ and the total time difference importance indicator $T_s$ can be used to obtain a comprehensive resource importance evaluation indicator $w_s$:

$$w_s = w_{C_s} \times C_s + w_{P_s} \times P_s + w_{T_s} \times T_s \tag{13}$$

where $w_{C_s}$, $w_{P_s}$, $w_{T_s}$ are the weight coefficients that signify the importance of cost, work, and time difference, respectively.

In actual scientific research projects, analytic hierarchy process (AHP) can be adopted according to the actual needs of the project.

After determining the weight $w_s$ of each resource and including it in the objective function of the equilibrium optimization model, the multi-resource equilibrium optimization model can be expressed as:

$$\begin{aligned} &\min \delta^2 = \sum_{s=1}^{m} w_s \delta_s^2 = \sum_{s=1}^{m} w_s \left[ \frac{1}{T} \sum_{t=1}^{T} \left( R_s(t) - \overline{R_s} \right)^2 \right] \\ &\text{s.t.} \\ &\qquad \begin{cases} R_s(t) = \sum R_{s,n}(t), \quad n = A, B, C, \dots, N \\ R_{s,n}(t) = \begin{cases} R_{s,n}, & TS_n \le t \le TS_n + D_n \\ 0, & \text{else} \end{cases} \\ \max(TS_m + D_m) \le TS_n \le LS_n \\ ES_n \le TS_n \le LS_n \end{cases} \end{aligned} \tag{14}$$

where $R_s(t)$ is the intensity value of the required resource $s$ in the entire scientific research project at time $t$; $R_{s,n}(t)$ is the intensity value of the required resource $s$ at work $n$ at time $t$; $\overline{R_s}$ is the average resource intensity of resource $s$ in the entire scientific research project; $R_{s,n}$ is the intensity value of resource $s$ required by job $n$; $T$ is the research project cycle; $ES_n$ is the earliest start time of job $n$; $TS_n$ is the actual start time of work $n$; $LS_n$ is the latest start time of job $n$; $D_n$ is the implementation cycle of job $n$; $m$ is the job number immediately preceding job $n$.

## 5. Examples of Experimental Simulation and Optimization Effect Analysis.

**5.1. Example test data.** To experimentally verify the optimization effect of the pigeon colony algorithm for multi-resource equilibrium of scientific research projects, based on [22], an example labor division for a scientific research project is shown in Table 2.

TABLE 2. Example test data

| $n$ | $m$ | $ES_n$ | $LS_n$ | $D_n$ | $R_{s,n}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ |
| $A$ | – | 1 | 3 | 2 | 8.8 | 4.5 | 4.4 | 1.5 | 4.2 |
| $B$ | – | 3 | 10 | 7 | 2.9 | 0 | 6.6 | 5.6 | 0 |
| $C$ | $A$ | 4 | 5 | 4 | 3.6 | 3.3 | 0 | 0 | 4.2 |
| $D$ | – | 4 | 7 | 3 | 8.9 | 1.3 | 5.4 | 2.8 | 1.0 |
| $E$ | $C$ | 8 | 10 | 4 | 0 | 0.7 | 3.2 | 0 | 1.0 |
| $F$ | $D$ | 9 | 11 | 3 | 1.2 | 0 | 2.6 | 1.7 | 2.0 |
| $G$ | – | 7 | 10 | 8 | 3.8 | 1.1 | 1.5 | 3.2 | 0 |
| $H$ | $E\&F$ | 12 | 15 | 3 | 4.9 | 4.4 | 4.8 | 5.5 | 4.6 |
| $I$ | – | 9 | 10 | 5 | 7.2 | 5.6 | 0 | 0 | 0 |
| $J$ | – | 8 | 12 | 6 | 4.2 | 3.9 | 0 | 1.2 | 1.2 |
| $K$ | $I$ | 14 | 16 | 2 | 4.6 | 4.8 | 5.6 | 4.7 | 0 |

This research project includes $[A, B, C, \ldots, K]$, a total of 11 jobs, has a total of 5 resources, and the project cycle $T$ is 17 days. In addition to a limitation on the implementation period $D_n$, each job also has a limitation in its start time, i.e., the actual start time $TS_n$ of each job must be between the earliest start time $ES_n$ and the latest start time $LS_n$.

In addition, some tasks can only be undertaken after some other work is completed. For example, work $C$ cannot be performed until work $A$ is completed. In Table 1, different resources $R_1 \sim R_5$ have different resource intensity values for different jobs with a higher value indicating a greater demand for that resource for the job. A value of 0 indicates that the job does not require that resource.

**5.2. Determination of the weight coefficient of each resource in the objective function.** In actual scientific research projects, the three weight coefficients of $w_{C_s}$, $w_{P_s}$, $w_{T_s}$ in Formula (13) can be calculated based on the actual needs of the project using the analytic hierarchy process (AHP) [23]. The AHP method is a research method for calculating decision weights by combining qualitative and quantitative solutions to solve multi-objective complex problems. The steps of calculating these three weight coefficients are as follows.

1) Determine scale and construct judgment matrix

This example is intended to use the 1-5 scale method. The experts will compare the cost, work, and time difference in pairs based on their own experience and the needs of the project. The scores will form a judgment matrix $T$.

2) Solve the maximum eigenvalue ($\lambda_{\max}$) of the matrix $T$ and the corresponding eigenvector. The eigenvector is normalized to the weight coefficient $w_{C_s}$, $w_{P_s}$, $w_{T_s}$.

3) Consistency check analysis

When constructing the judgment matrix, there may be logical errors. For example, $A$ is more important than $B$, $B$ is more important than $C$, but $C$ is more important than $A$.

Therefore, it is necessary to use a consistency check to examine whether the error occurs in the matrix $T$. Calculate $CR = 0.5(\lambda_{\max} - 3)/RI$. If the $CR$ value is less than 0.1, it means that the matrix $T$ has passed the consistency check. Otherwise, it means that the consistency check has not been passed, and the judgment matrix $T$ needs to be modified. The value of $RI$ can be obtained by directly checking the table.

After inviting many experts and scholars to conduct in-depth research on the evaluation indicators of this model, we obtained a judgment matrix $T$.

$$T = \begin{bmatrix} & C_s & P_s & T_s \\ C_s & 1 & 3 & 3 \\ P_s & 1/3 & 1 & 1/3 \\ T_s & 1/3 & 3 & 1 \end{bmatrix}$$

Solve the eigenvalues and eigenvectors of the matrix $T$ and check the consistency. The results are shown in Table 3.

Table 3. Calculation result of weight coefficient

| $\lambda_{\max}$ | $RI$ | $CR$ | $w_{C_s}$, $w_{P_s}$, $w_{T_s}$ |
|---|---|---|---|
| 3.054 | 0.58 | 0.047 | [0.589 0.247 0.164] |

In Table 3 $CR < 0.1$, it indicates that the matrix $T$ has passed the consistency check, and the weight coefficients obtained are valid and can be used in Formula (13).

Each resource has a different contribution to the objective function in the mathematical model of resource equilibrium optimization. The data is preprocessed using a comprehensive evaluation system for resource importance in order to obtain the contribution $w_s$ of each resource.

The total cost $C(Q_s)$ of resource $s$ for the scientific research project can be obtained as the product of the resource demand and the cost. For simplicity of calculation, the unit price of each resource is set to be the same as $C_{R_s} = 1$, as shown in Formula (15).

$$C(Q_s) = Q_s \times C_{R_s} \tag{15}$$

Taking resource $R_1$ as an example, calculate $P(Q_1)$, $T(Q_1)$, and $C(Q_1)$ values for resource $R_1$.

$P(Q_1)$ is the number of jobs that require resource $R_1$ for a scientific research project, which can be determined by observing the number of $R_1$ resource intensity values other than 0 in Table 1, that is:

$$P(Q_1) = \sum_{n=1}^{N} \operatorname{sgn}(R_{1,n}) = 10 \tag{16}$$

The working time difference is the difference between the latest start time and the earliest start time for the work. The total working time difference $T(Q_1)$ that resource $R_1$ will be occupied by the scientific research project can be determined as shown in Formula (17).

$$T(Q_1) = \sum_{n=1}^{N} (LS_n - ES_n) \times \operatorname{sgn}(R_{1,n}) = 28 \tag{17}$$

The total cost of resource $R_1$ for the scientific research project can be calculated using (18), where the total resource demand $Q_1$ is the product of the period for each job and the corresponding resource intensity value:

$$C(Q_1) = Q_1 \times C_{R_1} = \sum_{n=1}^{N} (D_n \times R_{s,n}) \times C_{R_1} = 172.9 \tag{18}$$

(16) to (18) can be used to calculate the remaining evaluation index parameters of each resource in turn, and (10)-(12) can then be used to calculate the work importance index $P_s$, the total time difference importance index $T_s$ of each resource and the cost importance index $C_s$. Finally, (13) is used to obtain the weight coefficients of various resources in the model objective function. The calculation results are shown in Table 4.

Table 4. Comprehensive evaluation index of the importance of each resource

| Evaluation index | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $R_5$ |
|---|---|---|---|---|---|
| $P(Q_s)$ | 10 | 9 | 8 | 8 | 7 |
| $T(Q_s)$ | 28 | 21 | 24 | 26 | 17 |
| $C(Q_s)$ | 198.1 | 111.9 | 129.4 | 114.4 | 59.2 |
| $w_s$ | 0.289 | 0.187 | 0.207 | 0.197 | 0.120 |

The resource weight coefficients $w_s$ obtained by the solution can be substituted into the objective function Equation (14) of the resource equilibrium optimization model. Thus, the objective function of the resource equilibrium optimization can be obtained, as shown in Equation (19) for this example.

$$\min \delta^2 = 0.289\delta_1^2 + 0.187\delta_2^2 + 0.207\delta_3^2 + 0.197\delta_4^2 + 0.12\delta_5^2 \tag{19}$$

5.3. **Effect analysis of pigeon population algorithm in multi-resource equilibrium optimization.** The proposed method shown in Table 1 has been coded in Matlab to optimize the resource balance of the example scientific research project. The algorithm test parameters are shown in Table 5 below.

Table 5. Algorithm test parameters

| Parameter | Value |
|---|---|
| Map & Compass operator $R$ | 500 |
| Total number of pigeons $N_p$ | 11 |
| Dimension of solution space $d$ | 0.08 |
| Landmark operator maximum iterations $T_2$ | 35 |
| Map & Compass operator maximum iterations $T_1$ | 10 |

As can be seen from Table 5, there are fewer parameters that need to be adjusted for the pigeon algorithm and the program can be debugged more easily, which is an advantage not shared by other bionic intelligent algorithms. After parameter debugging has been completed several times, the parameters shown in Table 5 can be substituted into the algorithm program to obtain satisfactory results.

The core principle of the pigeon population algorithm is that as the number of iterations increases, the pigeon population will reduce from an initial large population to a smaller population with an optimal direction, and the value $\delta^2$ of the objective Function (14) for the same multi-source equilibrium optimization gradually moves towards minimization of the direction approximation. Since the initial population generated by the pigeon population algorithm is random, the resource equilibrium variance value $\delta^2$ that corresponds to the initial population will be different and thus the optimal population obtained after each operation is also different; however, an optimal solution can be obtained. This article arbitrarily selects a single calculation result to analyze the effect of the algorithm. Figure 1 shows the variation curve of the resource equilibrium variance $\delta^2$ as the number of iterations increases.

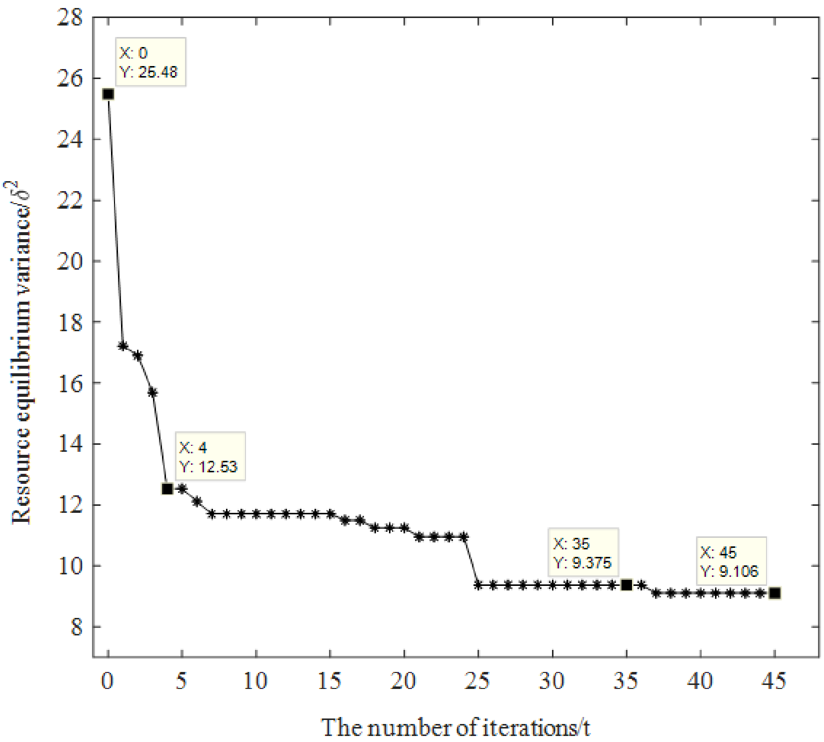


FIGURE 1. Curve of resource equilibrium variance with iteration number

This example performs a total of 45 iterations of the pigeon algorithm, where the 0th time is the initial optimal individual of the initial population that is randomly generated. It can be seen from Figure 1 that over the first four iterations, the variance value $\delta^2$ of the resource balance drops the fastest, dropping from 25.48 at the beginning to 12.53 and then slowly decreasing until it finally stabilizes at 9.106. $\delta^2$ dropped the fastest in the first 35 iterations of the Map & Compass operator, while for the Landmark operator, it fell more slowly, decreasing slightly and finally stabilizing over the remaining 10 iterations. The overall iterative process was relatively smooth and a project work plan arrangement with a small variance in multi-resource equilibrium was finally obtained.

The obtained optimized results are shown in Table 6 and Figure 2 and compare the optimal individual in the 45th iteration with the optimal individual in the initial population.

Table 6 shows that the optimized work plan arrangement using the pigeon colony algorithm has a more balanced use of resources and a lower resource intensity value than the

TABLE 6. Example test results

| Plan | Work plan in the project | | | | | | | | | | | min $\delta^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial plan | 1 | 9 | 4 | 6 | 9 | 11 | 8 | 15 | 9 | 12 | 14 | 25.484 |
| Best plan | 1 | 3 | 5 | 4 | 10 | 10 | 7 | 14 | 9 | 12 | 16 | 9.106 |
| Plan 1 | 1 | 3 | 5 | 4 | 10 | 11 | 7 | 14 | 9 | 12 | 16 | 9.374 |
| Plan 2 | 1 | 3 | 5 | 4 | 10 | 11 | 8 | 15 | 10 | 8 | 16 | 10.952 |

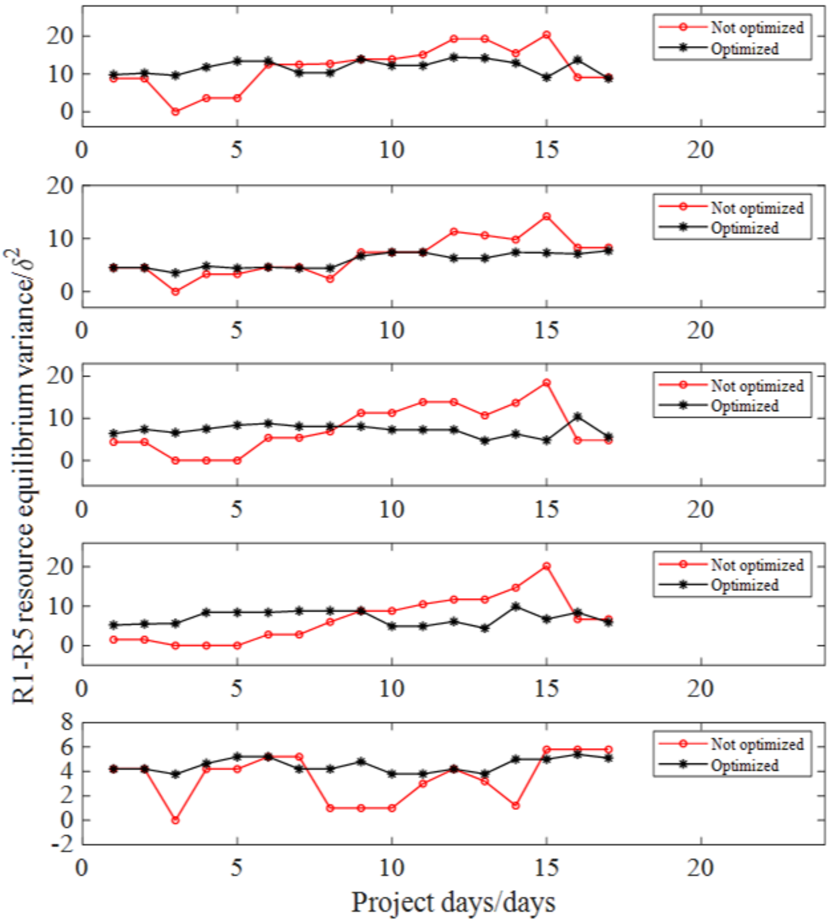


FIGURE 2. The equilibrium variance of each resource over the project cycle

initial plan before balanced optimization, thus achieving a very good overall optimization effect. Additionally, Table 6 also provides a solution that has a relatively small variance in resource balance which can be used by scientific research project managers according to the actual situation.

The resource balance optimization results not only reflect the smaller variance of the overall resource balance, but also reflect the daily usage demands for the $R_1 \sim R_5$ 5 resources in the project cycle. Figure 2 shows the daily resource intensity curve for various project resources before and after balanced optimization.

It can be seen from Figure 2 that before resource balance optimization was performed, there were high fluctuations in resource intensity of each resource during the project cycle. Peaks and troughs also repeatedly appeared for individual resources and the resources were unevenly used which is unfavorable to the implementation of scientific research projects. After optimization using the pigeon colony algorithm, the intensity curve for the usage of each resource becomes very smooth across the project cycle, eliminating the phenomenon of peaks and valleys. This shows that the pigeon colony algorithm has achieved very effective optimization of multi-project resources.

6. **Conclusion.** This article uses a pigeon colony optimization algorithm to consider the cost, importance, and total time difference of resources to establish a resource importance evaluation system that can be used to optimize resources across the fixed period of scientific research projects and address any possible imbalance in resource usage. The

goal of the algorithm is to minimize resource equilibrium variance and reasonably divide project work in order to achieve a balanced use of resources in the project cycle and avoid the phenomenon of peaks and valley. The balanced use of multiple resources in scientific research projects is of great significance to reduce scientific research fund usage and complete the project's stated goals on time and with high quality. Therefore, this paper has explored the pigeon colony algorithm which has important practical value and significance to obtain multi-resource equilibrium of scientific research projects.

However, the multi-resource equilibrium optimization model established in this article is relatively simple and has certain assumptions. It does not take account of various unexpected situations that may occur during the project. Therefore, the establishment of a dynamic resource equilibrium optimization analysis model is also the direction of future researches. At the same time, the parameters in the pigeon algorithm are fixed values, using adaptive parameters to make the algorithm converge faster is also the focus of the following research. Finally, a combination of the pigeon algorithm and other intelligent algorithms is combined into a hybrid algorithm, and its advantages may be complementary to obtain better results.

**Acknowledgment.** This work is partially supported by National Natural Science Foundation of China under Grant 51607027 and the Fundamental Research Funds for the Central Universities under Grant xzy012019040. The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

## REFERENCES

[1] N. Pang, Y. You and Y. Shi, Application research on the simulated annealing in balance optimization of multi-resource network planning, *The 2nd International Symposium on Intelligent Information Technology Application*, pp.113-117, 2008.

[2] C. Li, H. Zhang, H. Zhang and Y. Liu, Short-term traffic flow prediction algorithm by support vector regression based on artificial bee colony optimization, *ICIC Express Letters*, vol.13, no.6, pp.475-482, 2019.

[3] J. Huang, X. Wang and R. Chen, Genetic algorithms for optimization of resource allocation in large scale construction project management, *JCP*, vol.5, no.12, pp.1916-1924, 2010.

[4] M. Şahin and T. Kellegöz, A new mixed-integer linear programming formulation and particle swarm optimization based hybrid heuristic for the problem of resource investment and balancing of the assembly line with multi-manned workstations, *Computers & Industrial Engineering*, vol.133, pp.107-120, 2019.

[5] P. B. Myszkowski, M. E. Skowroñski, Ł. P. Olech et al., Hybrid ant colony optimization in solving multi-skill resource-constrained project scheduling problem, *Soft Computing*, vol.19, no.12, pp.3599-3619, 2015.

[6] C. Li and H. Duan, Target detection approach for UAVs via improved pigeon-inspired optimization and edge potential function, *Aerospace Science and Technology*, vol.39, pp.352-360, 2014.

[7] J. Gang, J. Xu and Y. Xu, Multiproject resources allocation model under fuzzy random environment and its application to industrial equipment installation engineering, *Journal of Applied Mathematics*, 2013.

[8] P. Ghoddousi, E. Eshtehardian, S. Jooybanpour and A. Javanmardi, Multi-mode resource-constrained discrete time-cost-resource optimization in project scheduling using non-dominated sorting genetic algorithm, *Automation in Construction*, vol.30, pp.216-227, 2013.

[9] D. Debels and M. Vanhoucke, A decomposition-based genetic algorithm for the resource-constrained project-scheduling problem, *Operations Research*, vol.55, no.3, pp.457-469, 2007.

[10] W. P. Wu, J. X. Liu and Y. Zhang, Project goal balanced optimization research based on generalized cost, *Applied Mechanics and Materials*, vols.174-177, pp.2966-2969, 2012.

[11] S. Al-imran, M. Fuad, T. Ahmed, M. Ali and M. Maruf, Optimization of distributed energy resources to balance power supply and demand in a smart grid, *The 3rd International Conference on Green Energy and Technology (ICGET)*, pp.1-5, 2015.

[12] R. Zhou, C. Ye and H. Ma, Model research of multi-objective and resource-constrained project scheduling problem, in *The 19th International Conference on Industrial Engineering and Engineering Management*, E. Qi, J. Shen and R. Dou (eds.), Berlin, Heidelberg, Springer, 2012.

[13] H. Qiu and H. Duan, Multi-objective pigeon-inspired optimization for brushless direct current motor parameter design, *Science China Technological Sciences*, vol.58, no.11, pp.1915-1923, 2015.

[14] S. B. Chen, H. Zhang and J. Zhang, Research and application on the reactive power optimization of the regional grid planning, *Advanced Materials Research*, vols.732-733, pp.920-925, 2013.

[15] Z. Hu, Research on application of BP neural network based on genetic algorithm in multi-objective optimization, *The 8th International Conference on Information Technology in Medicine and Education (ITME)*, Fuzhou, pp.681-684, 2016.

[16] I. Chub, M. Novozhylov and M. Murin, Optimization problem of allocating limited project resources with separable constraints, *Cybernetics and Systems Analysis*, vol.49, no.4, pp.632-642, 2013.

[17] O. B. Haddad, M. Mirmomeni, M. Z. Mehrizi and M. A. Mariño, Finding the shortest path with honey-bee mating optimization algorithm in project management problems with constrained/unconstrained resources, *Computational Optimization and Applications*, vol.47, no.1, pp.97-128, 2010.

[18] Y. Zhang and Y. Xu, The research of multi-resource leveling optimization in critical chain management, *The 2nd International Conference on Information Science and Engineering*, Hangzhou, pp.780-783, 2010.

[19] C. Fang, F. Marle, M. Xie and E. Zio, An integrated framework for risk response planning under resource constraints in large engineering projects, *IEEE Trans. Engineering Management*, vol.60, no.3, pp.627-639, 2013.

[20] L. You, D. Yuan, L. Lei, S. Sun, S. Chatzinotas and B. Ottersten, Resource optimization with load coupling in multi-cell noma, *IEEE Trans. Wireless Communications*, vol.17, no.7, pp.4735-4749, 2018.

[21] J. Liu, H. Zhang and G. Xu, An anomaly detector deployment awareness detection framework based on multi-dimensional resources balancing in cloud platform, *IEEE Access*, vol.6, pp.44927-44933, 2018.

[22] Y. Yi, X. Li and C. Gu, Hybrid particle swarm optimization for multiobjective resource allocation, *Journal of Systems Engineering and Electronics*, vol.19, no.5, pp.959-964, 2008.

[23] M. Younas, S. H. I. Jaffery, M. Khan et al., Multi-objective optimization for sustainable turning Ti6Al4V alloy using grey relational analysis (GRA) based on analytic hierarchy process (AHP), *The International Journal of Advanced Manufacturing Technology*, vol.105, nos.1-4, pp.1175-1188, 2019.