Intelligent Allocation Method of Earthwork Based on Sparrow Search Algorithm

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Abstract: The calculation of earthwork volume is an important link in controlling project investment, project budget, and construction arrangement in the construction process of highways, tunnels, bridges, and other engineering projects. It has a direct impact on project progress and project budget. To ensure effective cost and schedule control, it is necessary to conduct fast and accurate calculation of earthwork quantities, and consider on-site factors for real-time dynamic control of earthwork allocation optimization. This study establishes a whole construction process allocation model and intelligent allocation algorithm for earthwork. The allocation equation and constraint conditions are established through the classification of earthwork operation areas, and the SSA algorithm is used to calculate and analyze the optimal allocation plan with the least cost. The calculation results show that the SSA algorithm is highly consistent with the actual situation for the optimal solution of nonlinear engineering allocation amount, with a relative error rate as low as 1. 13%, and the calculation process is efficient, taking only 313 seconds, fully proving its economic and practical value in engineering practice.

Keywords: SSA algorithm; Earthwork allocation; Earthwork construction; Control model.

1 Introduction

The problem of earthwork allocation is commonly present in many civil engineering projects such as embankments, site leveling, underground construction, and earth rock dams, with different types of civil engineering considering different focuses of the problem. As a key link in civil engineering, earthwork allocation has a crucial impact on the cost, schedule, and quality of the project. Therefore, in-depth research on earthwork allocation issues and the establishment of effective allocation models are of great

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significance for improving the overall efficiency of civil engineering. The current research on earthwork allocation mainly focuses on two aspects: firstly, creating a earthwork allocation model that considers specific engineering characteristics; The second is to search for more suitable algorithms to optimize the existing earthwork allocation plan. Liu Zhixin et al. [1] established an optimized earthwork allocation model for mechanical equipment and other resources based on the dynamic changes during the construction process of rockfill dams; Zhou Hougui et al. [2] systematically summarized the research work on earthwork allocation; Chen Xiutong et al. [3], Li Xiaowei et al. [4], Huang Binghu et al. [5], and Wang Renchao et al. [6] respectively conducted feasibility studies on the optimized earthwork[7-8] scheme obtained from calculations using improved particle swarm optimization algorithm, linear programming method, ant colony algorithm, and Monte Carlo tree algorithm[9]. In response to the complex construction conditions of the face rockfill dam of Wuyue Pumped Storage Power Station, combined with the above research results and fully considering various uncertain factors[10], a suitable earthwork allocation model for engineering needs is established, and particle swarm optimization and genetic algorithm are used to calculate the established model separately, in order to obtain a earthwork allocation plan that is suitable for the actual engineering situation and optimize the seven earthwork allocation plan.

2 Optimization and Allocation Model of earthwork Based on Sparrow Search Algorithm

2.1 Control Equation and Constraint Conditions of Earthwork Allocation Model

The modeling approach of the earthwork allocation model is as follows: taking the minimum cost of the entire earthwork allocation cycle as the objective function, comprehensively considering the quantitative and qualitative constraints in the allocation process. In order to express the spatiotemporal relationship of earthwork allocation, the allocation process is divided into a series of construction sequences, and the dynamic transfer of materials is statically described. The entire allocation process is viewed as a whole, and the allocation balance planning is optimized. The model assumes that the project has completed preliminary work such as terrain design, borrow and abandon area planning, and construction progress. The objective function is as follows:

$$minZ = \sum_{i=1}^{N_a}\sum_{j=1}^{N_b} C_{W_iT_j}Q_{W_iT_j} + \sum_{k=1}^{N_b}\sum_{j=1}^{N_k} C_{B_kT_j}Q_{B_kT_j} + \sum_{i=1}^{N_a}\sum_{q=1}^{N_q} C_{W_iQ_q}Q_{W_iQ_q} \quad (1)$$

In the formula: N_a, N_b, N_k, N_q - the number of excavation, filling, borrowing, and abandonment areas; W_i, T_j, B_k, Q_q - numbers of excavation, filling, borrowing, and abandonment areas; C_{WiTj}, Q_{WiTj} - Unit earthwork cost (yuan/m^3) and allocation amount (m^3) from excavation area W_i to filling area T_j; C_{BkTj}, Q_{BkTj} - Unit earthwork cost (yuan/m^3) and allocation amount (m^3) from the borrowing area B_k to the filling area T_j; C_{WiQq}, Q_{WiQq} - Unit earthwork allocation cost (yuan/m^3) and allocation amount (m^3) from excavation area W_i to disposal area Q_q.

The basic constraints are as follows:

(1) Material conservation constraint

The total amount of soil and rock that can be excavated in a certain excavation area should be equal to the sum of the soil and rock transported from the excavation area to each fill and abandoned area; The amount of earthwork that needs to be filled in a certain filling area should be equal to the sum of the earthwork allocated from each area to this area:

$$\sum_{i=1}^{N_a} Q_{W_iT_j} + \sum_{k=1}^{N_k} Q_{B_kT_j} = Q_{T_j} \tag{2}$$

$$\sum_{j=1}^{N_b} Q_{W_iT_j} + \sum_{i=1}^{N_q} Q_{W_iQ_q} = Q_{W_i} \tag{3}$$

In the formula, Q_{Tj} represents the amount of soil and rock required to reach the design soil and rock volume in the filling area with the number T_j, and Q_{Wi} represents the amount of soil and rock that needs to be excavated in the excavation area with the number W_i.

(2) Capacity limit constraint

The total volume transported to the disposal site shall not exceed the capacity of the current disposal site; The total volume of earthwork allocated from the borrow pit to each filling area shall not exceed the capacity of the borrow pit.

$$\sum_{j=1}^{N_b} Q_{B_kT_j} \le Q_{B_k} \tag{4}$$

$$\sum_{j=1}^{N_b} Q_{W_iQ_q} \le Q_{Q_q} \tag{5}$$

In the formula, Q_{Bk} is the capacity of the borrowing yard with the number Bk, and Q_{Qq} is the capacity of the disposal yard with the number Q_q. The objective function and constraint conditions of the above modeling ideas involve numerous variables and are complex to express. Combined with the sparrow search algorithm, the earthwork allocation can be heuristic searched for the earthwork allocation path. In other words, during the allocation process, the construction sequence can be clarified based on regional attributes, further optimizing the earthwork allocation model and uniformly expressing cost variables. Below is an explanation of the earthwork allocation model considering the construction sequence.

2.2 Sparrow Search Algorithm

Proposed the Sparrow Search Algorithm (SSA) based on the biomimetic principles of sparrow foraging and anti predation. In the SSA algorithm, the sparrow population has two identities, the first being discoverer or joiner, and the second being scout. The discoverer commands and leads the followers to search for foraging areas and directions; The remaining sparrows follow and monitor the discoverer to obtain food and other resources, known as joiners; Part of the first two groups also have a second identity - reconnaissance, detecting risk factors such as predators and engaging in anti predation behavior.

The location of the discoverer has been updated as follows:

$$x_{i,j}(t+1) = \begin{cases} x_{i,j}(t).\,exp(\frac{-i}{\alpha T}) & R_2 < ST \\ x_{i,j}(t) + QL & R_2 \geq ST \end{cases} \tag{6}$$

In the formula, t represents the current iteration count, T represents the maximum iteration count, x_i, $j(t)$ represents the position information value of the sparrow at the dimension iteration count t, α is a random number of [0, 1], R_2 ($R_2 \in [0, 1]$) represents the warning value, ST ($ST \in [0.5, 1]$) represents the safety value, Q is a random number that follows a normal distribution, and L represents a $1 \times d$ matrix where each element inside is 1. When $R_2 < ST$, it indicates that there are no predators around and the discoverer can conduct a large-scale search; When $R_2 \geqslant ST$, the investigator detects a predator and immediately sends out an alarm signal, causing all sparrows to quickly fly to other safe areas.

The location of the joiner has been updated as follows:

$$x_{i,j}(t+1) = \begin{cases} Q.\,exp(\frac{x_{worst}(t) - x_{i,j}(t)}{i^2}) & i < \frac{N}{2} \\ x_{bestj}(t+1) + |x_{i,j}(t) - x_{bestj}(t+1)|A^{+}L & R_2 \geq ST \end{cases} \tag{7}$$

In the equation, $x_{worst}(t)$ represents the current global worst position, $A+=AT(AAT)$-1, A represents a $1 \times d$ matrix with randomly assigned internal elements of 1 or -1, AT is the transpose of A, and x_{bestj} (t) represents the best position occupied by the discoverer. When $i>n/2$, it indicates that the participant with poor fitness is in a hungry state and needs to fly in other directions to find food.

Scouts generally make up 10% to 20% of the population, and the location update formula is as follows:

$$x_{i,j}(t+1) = \begin{cases} x_{bestj}(t) + \beta|x_{i,j}(t) - x_{bestj}(t)| & f_i > f_g \\ x_{i,j}(t) + K\left[\frac{|x_{i,j}(t) - x_{worst}(t)|}{(f_i > f_w) + e}\right] & f_i = f_g \end{cases} \tag{8}$$

In the formula, $x_{bestj}(t)$ represents the current global best position, β is the step control parameter of a normally distributed random number with a mean of 0 and a variance of 1, K ($K \in [-1, 1]$) represents the direction of sparrow motion and is also the step control parameter, fi represents the fitness value of the sparrow, f_g and f_w represent the current global best value and worst value, respectively, and e is a constant to avoid a denominator of 0. When $f_i > f_g$, it indicates that sparrows are at the edge of the population and are vulnerable to predator attacks; When $f_i = f_g$, it indicates that sparrows in the middle of the population are aware of the danger and therefore need to approach other sparrows to reduce the probability of being preyed upon.

2.3 Sparrow Search Algorithm

(1) Establish a database for earthwork zoning, excavation, filling, and transportation prices, and set corresponding sparrow individuals.

(2) Initialize the sparrow population and calculate the fitness values of each sparrow by setting the control equation and constraint conditions for earthwork allocation. Find the current optimal and worst fitness values, as well as their corresponding positions.

(3) Select some sparrows with better fitness values as discoverers and update their positions.

(4) The remaining sparrows serve as followers.

(5) Randomly select a portion of sparrows as scouts and update their positions using a formula.

(6) Determine whether the end condition has been met. If so, proceed to the next step. Otherwise, proceed to step (2).

(7) After adjusting the prediction model, it is embedded into the smart earthwork management system to achieve intelligent control of earthwork operations.

The entire algorithm process is shown in Figure 1.

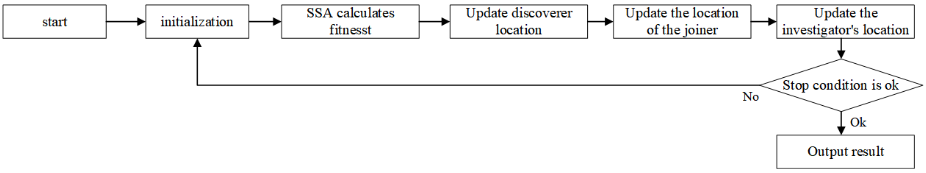

Fig. 1. SSA optimized earthwork allocation process

3 Application Cases

The research object is the allocation of earthwork and rock engineering for the Youth Hub of Pinglu Canal in Guangxi Province. The terrain of this project is complex and the deployment distance is long. Considering the characteristics of the project, it is particularly important to consider the construction sequence.

3.1 Data Preprocessing

The first step is to gather the original topographic map and design topographic map data of the research area, which may include contour information. If the data is in paper form, it needs to be converted into electronic documents through scanning technology and further vectorized for digital operation. If the data already exists in CAD format, it needs to be converted to a widely compatible. shp vector format and a unified coordinate system needs to be set to ensure the geometric accuracy of the data. In the absence of a direct topographic map, on-site surveying of the study area can be chosen to obtain necessary elevation point data. Subsequently, using these elevation points or contour information, an irregular triangulation network (TIN) is constructed, and a digital elevation model (DEM) is generated from the TIN. The construction of the DEM model in this project relies heavily on the conversion and processing flow of CAD format data. The specific conversion and processing details are shown in Figure 2.

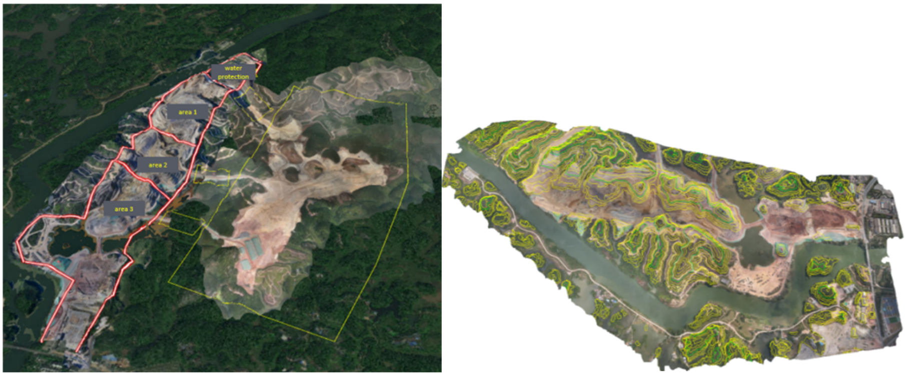

Fig. 2. Terrain data processing process

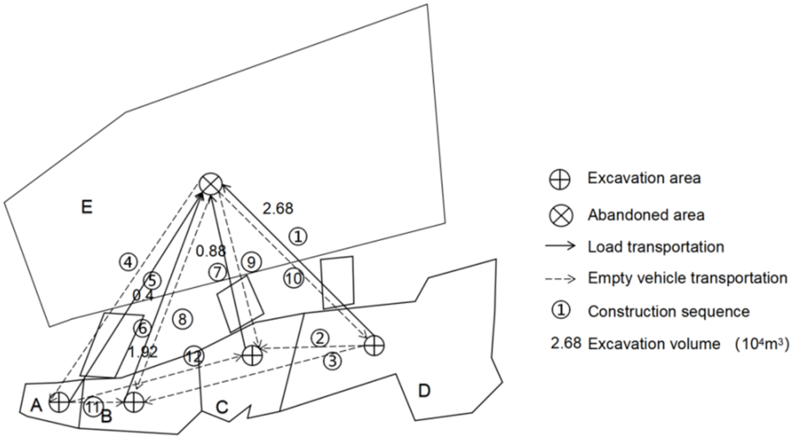

Fig. 3. Distribution of Excavation and Filling Areas

For the convenience of vehicle allocation and transportation analysis, four excavation work areas (A, B, C, D) and one abandoned excavation work area (E) are divided. The optimal allocation plan is analyzed through the SSA based earthwork allocation model to determine the engineering vehicle allocation route and daily excavation volume. The schematic diagram is shown in Figure 3. The linear programming method can only obtain the excavation volume of the corresponding area and cannot determine the specific transportation direction, while the SSA algorithm can provide the transportation direction, which is convenient for operators to plan the daily earthwork allocation route and volume, ensuring smooth construction.

3.2 Experimental and Analytical Results

To demonstrate the feasibility of the method proposed in this article, the cost unit price per earthwork unit is set to 1 yuan/$m^3 \cdot$ km. Linear programming and basic ant colony algorithm are used again to solve the earthwork allocation problem of this project. The minimum cost obtained by linear programming is 4. 441 million yuan. Due to not considering the construction sequence, it is not possible to use vector graphics for intuitive representation; The minimum costs obtained by the basic ant colony algorithm and simulated annealing algorithm are 4. 578 million and 4. 614 million yuan, respectively; The minimum cost obtained using the method described in this article is 4. 457 million yuan. According to Table 1, on the one hand, compared with linear programming, intelligent algorithms have significant advantages in considering nonlinear factors, construction sequence, and expression methods. At the same time, they can also obtain several optimal allocation schemes at once. On the other hand, the minimum cost relative errors of the basic ant colony algorithm and simulated annealing algorithm are about 2. 85% and 3. 66%, respectively, and the running times are 415. 4 seconds and 377. 21 seconds, respectively, indicating low running efficiency. Compared with the basic ant colony algorithm, the minimum cost obtained by the SSA algorithm used in this paper is closer to the optimal cost obtained by linear programming method, with a relative error of 1. 13%. The running time is shortened by about 102 seconds and 64. 08 seconds respectively, improving the running efficiency.

Table 1. Comparison between Intelligent Algorithm and Linear Programming Algorithm

Allocation algorithm	Minimum cost/Million yuan	Running time/s	Nonlinear factors	Construction sequence	Expression method	Allocation plan
Linear programming method	4. 451	5. 00	Approximate linearization	Not considering	Allocation Table	only
Basic Ant Colony Algorithm	4. 578	415. 40	Possible consideration	consider	Vector diagram	some
Simulated Annealing Algorithm	4. 614	377. 21	Possible consideration	consider	Vector diagram	some
SSA algorithm	4. 457	313. 13	Possible consideration	consider	Vector diagram	some

4 Conclusion

This study constructed a comprehensive earthwork scheduling model that integrates construction sequence, direction planning, and optimization of allocation quantities. The model significantly enhances the descriptive ability of the earthwork allocation process, aiming to provide technical management and on-site operation teams with both economical, efficient, and easy to understand operational guidelines. The core contributions of this chapter are reflected in the following aspects:

(1) Innovative integration of SSA algorithm and earthwork allocation: By cleverly combining the complex earthwork allocation process with SSA algorithm, this model effectively overcomes the limitations of traditional linear programming methods in

dealing with nonlinear constraints and achieves deep cost reduction in allocation. The example verification shows that the optimal solution obtained by this method is highly consistent with the actual situation, with a relative error rate as low as 1. 13%, and the calculation process is efficient, taking only 313 seconds, fully proving its economic and practical value in engineering practice.

(2) Visualization of construction sequence oriented allocation plan: This method pays special attention to the reasonable arrangement of construction sequence, and the generated allocation plan is not only accurate, but also further converted into detailed vector guidance diagrams. This innovative measure greatly facilitates the transmission of on-site information, allowing construction personnel to intuitively understand the amount of earthwork to be mobilized, clear construction sequence, and optimal movement path, providing strong support for precise guidance of the construction process.

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