Multi-objective Optimization of Construction Projects Based on Ant Colony Algorithm

Jin Chen

Shandong Vocational College of Science and Technology, Weifang, Shandong,261053 China

liyt882@126.com

Abstract. To understand the multi-objective optimization of construction projects, a multi-objective optimization study of construction projects based on ant colony algorithm has been proposed. This paper first proposes a multi colony ant colony particle swarm fusion algorithm, and conducts empirical research on the algorithm based on a subway project example. Based on the analysis of the solution effectiveness, it is concluded that this algorithm obtains more Pareto solution sets than the basic ant colony algorithm when solving multi-objective joint optimization problems, and can be applied to integrated management of construction projects.

Keywords: Ant colony algorithm; Construction engineering; Multi-objective optimization.

1 Introduction

With the development of material production and social economy, modern people have increasingly high requirements for the layout of construction projects. The layout of a building largely determines its functionality, practicality, comfort, and aesthetics, and is crucial for various types of buildings. However, in practical construction projects, due to the contradiction between multiple objectives, it is often difficult to meet all objectives simultaneously, and the overlapping interests are more complex, resulting in significant optimization problems in building layout. Faced with such problems, people are gradually beginning to search for new methods to solve layout optimization problems. Among them, the multi-objective layout optimization method based on ant colony algorithm has become one of the more effective solutions[1]. Ant colony algorithm is an algorithmic method developed by imitating the foraging and pathfinding behavior of ants in nature. The core idea of this algorithm is to utilize the mechanism of pheromone deposition and volatilization used by ants when searching for food, in order to obtain the global optimal solution. By utilizing this natural behavioral characteristic, designers abstract the process of ants searching for food into an optimization problem. The algorithm that enables the behavior rules of ants and the deposition and volatilization of pheromones represents the search strategy of the optimization process.

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Multi objective layout optimization aims to optimize the building layout scheme while meeting multiple objectives, so that the layout scheme can reach the optimal state. Compared to single objective problems, multi-objective problems are often more complex, and the effectiveness and accuracy of optimization results are also more difficult to ensure. In this case, the advantages of ant colony algorithm are obvious. By simulating the deposition and volatilization of pheromones during the process of ants searching for food, ant colony algorithm can avoid getting stuck in local optima and unable to escape. The multi-objective optimization of construction projects based on ant colony algorithm has some significant advantages compared to other methods, including global search ability, adaptability, and distributed computing. However, the specific effects may vary depending on the characteristics of the problem, parameter settings, and experimental conditions. Compared with traditional optimization methods such as genetic algorithm or simulated annealing, ant colony algorithm has stronger global search ability, which helps to find the global optimal solution of multi-objective problems. Compared with static algorithms, ant colony algorithm has strong adaptability and can make real-time adjustments according to changes in the problem. Compared with some algorithms that are prone to getting stuck in local optima, ant colony algorithm exhibits better robustness to a certain extent.

2 Building a multi-objective optimization problem model

2.1 Engineering Project Duration Model

This paper intends to use the dual code network diagram planning method to construct a duration function model. The dual code network plan diagram can clearly identify the earliest start time, latest completion time, and critical path of construction operations, which is beneficial for better control of construction progress. Assuming that the organization of each operation during the construction process is ideal, with neither idle work nor excess interval time, the corresponding duration of different construction operation methods will also vary. This paper assumes that each process is implemented using only one construction organization mode and cannot be mixed. Find the critical path of project construction from the dual code network diagram, and determine the total construction period by calculating the total time spent on each construction operation mode on the critical path[2-3]. Construct a mathematical model as shown in formula (1):

$$F_t = \sum_{A} t_{kj} \tag{1}$$

In the formula, tkj is the time taken to select the j-th operation mode when executing the k-th operation, k ∈ [1, n] (n: n operations are required to complete the project), j ∈ [1, m] (m: there are m operation modes for a certain operation); A is the collection of time spent on each key operation mode in the engineering project.

2.2 Engineering Project Cost Model

In constructing the engineering project cost model, this paper only considers the labor costs, material costs, and machinery usage costs incurred in each process operation mode. As the operation mode directly affects the duration of the project, the indirect costs generated by each operation mode are also different. The indirect cost is equal to the daily indirect cost multiplied by the total construction period. The specific cost mathematical model is as shown in formula (2):

$$F_c = \sum_{k=1}^{m} DG_{kj} + \sum_{A} t_{kj} \times IC \tag{2}$$

In the formula, DCkj represents the labor, material, and machine costs incurred in selecting the j-th operation mode for the k-th construction process; The indirect costs incurred by IC for selecting different operating modes.

2.3 Engineering Project Quality Model

The quality of engineering projects includes the quality of the building itself and its quality in the later operation process. This paper mainly studies the physical quality of construction engineering products. During the construction process, construction managers cannot pursue low costs and only ensure that the project quality meets the minimum standards specified by relevant laws, regulations, and investors. This paper invites experts to rate each operation mode on a percentage system and determine the weight of each individual process in the entire engineering project[4-5]. The quality model constructed as shown in formula (3):

$$F_q = \sum_{k=1}^{m} w_k \times q_{kj} \tag{3}$$

In the formula, wk is the quality weight corresponding to the k-th process; qkj is the quality score obtained after completing the work using the j-th construction organization method to execute the k-th process.

2.4 Construction of a multi-objective joint optimization problem model

After considering multiple factors, the target thresholds for construction period, cost, and quality have been determined, namely the latest construction period Tmax allowed by Party A, the maximum cost Cmax recognized by Party A, and the minimum quality standard Qmin required by Party A. Build a comprehensive model as shown in formula (4):

$$\begin{aligned} F_T &= \sum_A tk_j \\ F_c &= \sum_{k=1}^{n} DC_{kj} + \sum_A t_{kj} \times IC \\ F_Q &= \sum_{k=1}^{n} w_k \times q_{kj} \end{aligned} \tag{4}$$

2.5 Research on Ant Colony Particle Swarm Optimization Fusion Algorithm

(1)Ant Colony Algorithm Design

This problem belongs to the selection of construction methods and a typical integer programming problem. Each construction sub process is treated as a node, and each construction method is treated as a path between nodes. Different objective functions use different path length calculation methods to map the path problem to a solution space that can be solved by an ant colony algorithm. The implementation of ant colony algorithm starts from three aspects:

1) Initialize the amount of pheromones on each path to 0 and introduce a taboo table to store the paths traveled by each ant so that they do not repeatedly search. In this paper, the length of the taboo table is set to 1.

2) Ants construct paths. The probability of ants choosing the next task method to go through as shown in formula (5):

$$p_{ij}(t) = \left\{ \frac{[\tau_{ij}(t)][\eta_{ij}]}{\sum_0 [\tau_{ik}(\mathrm{t})]} \right\} \tag{5}$$

The above equation represents the probability of ants transitioning from process i to process j at time t. α is the relative importance of controlling pheromones; β is the heuristic factor (often represented by the reciprocal of d in TSP problems) that mainly controls the weight of the visibility of the path taken by ants when selecting the next process; Allowed is a collection of job patterns that ants can search for.

3) The operation of pheromones. When all ants find a solution set that matches the objective function, update the pheromone as shown in formula (6):

$$\tau_{\mathrm{ij}}(t+1) = \rho\tau_{ij}(t) + \Delta\tau_{ij}(t, t+1) \tag{6}$$

(2)Particle Swarm Optimization Algorithm Design

Obtain the position vector of each particle through real number encoding, corresponding to the decision variables of each dimension, calculate the objective function value through corresponding decoding methods, and continuously update the speed and position vector to complete the optimization of the objective function.

This problem belongs to integer programming, so the dimension of the particle is taken as the sub ordinal number, and the position of the i-th dimension is limited to

1~Ui, where Ui is the maximum optional construction method. After rounding the encoding of the dimension modification, the construction method of the i-th sub process is obtained.

Speed update method and position update method. Search the dimension space of each particle by the particle population. The displacement of each particle is written as xi=(xi1, xi2,..., xio), and the velocity of each particle itself is written as Vi=(Vi1, Vi2,..., vio).

There are two aspects to pay attention to when searching for particles:

1) Pi is the optimal position experienced by the particle during the search process, pi=(pi1, pi2,..., piq) (i=1, 2,..., n)

2) Pg is the optimal value obtained by all particles during the search process, pg=(Pg1, pg2,..., Pgq), where pg has only 2.

The velocity update formula for particles as shown in formula (7):

$$x_{id}^{k+1} = x_{id}^{k} + u_{id}^{k} \tag{7}$$

2.6 Fusion Algorithm Design

The concept of fusion algorithm design is to use the solution obtained from multiple group ACO as the initial solution of particles in multi-objective PSO, thereby providing a better search starting position for multi-objective PSO and improving search efficiency. Firstly, conduct ACO by setting up three populations for ants to search within each subgroup, archive the solution sets that meet the target requirements, and update pheromones; Secondly, use the solution obtained by the ant colony algorithm as the solution for initializing particles in PSO; Finally, perform a particle swarm optimization algorithm[6]. The specific algorithm steps are shown in Figure 1.

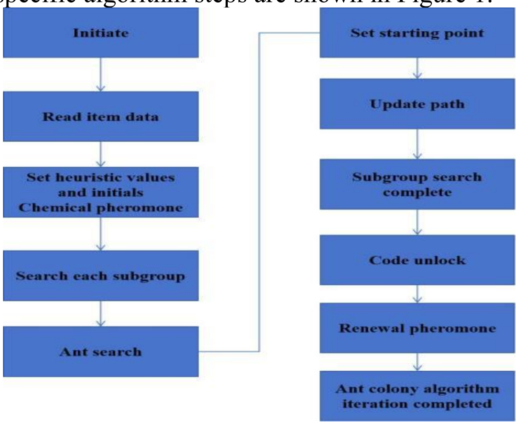

Fig. 1. Algorithm flow chart

3 Empirical analysis

We are currently using a subway project for example verification. The subway tunnel project is located in a muddy soil layer, coarse to medium sand layer, and pebble layer. The interval span is large and the construction period is long. A slurry shield machine is used for excavation, and a double track construction is adopted as the through tunnel. This paper intends to select the left line through process of the tunnel as the research object. The specific operation method data is shown in Table 1[7].

3.1 Algorithm parameter settings

In the ant colony algorithm, three populations are set, and after multiple simulations in the MATLAB environment and referencing literature, 70 ants are selected for each population. The number of iterations of the ant colony is 100, α =1, β = 4, p=0.1, Q0=1. In the parameter settings of the multi-objective particle swarm optimization algorithm, the population size is 65, the maximum number of iterations is 120, the inertia weight w=2, the individual learning coefficient c1=2.06, and the global learning coefficient c2=2.06.

Table 1. Construction operation parameters

Job serial number	Job name	Job content	Immediately after work	Operation mode	Time spent /d	Direct cost/ten thousand yuan	Quality weight of single operation (%)	Equal assignment quality
1	A	Reinforcement of originating and connecting ends of Houting Station	C，D	1，2,3	76 75 42	952 960 985	4.68 4.58 4.26	86 80 78
2	B	Supporting overlay construction behind shield	C，D	1，2	54 53	1023 1456 1026	2.06 2.06	84 85
3	C	Preparatory work for the start of left-line shield	E	1，2	62 63	108 109	8.34 8.35	86 87 84
4	D	Left Line Shield Initiation and 100m Trial Excavation	F	1，2	36 25	398 356	12.25 12.36	84 78

3.2 Experimental Results and Analysis

Simulate the basic ant colony algorithm and the multi colony ant colony particle swarm fusion algorithm in the MATLAB environment to obtain a three-dimensional scatter plot of the Pareto solution of the project's duration cost quality after the fusion of the two algorithms. The optimized construction processes of the two algorithms are shown in Table 2.

Table 2. Optimization Effect Diagram of Construction Scheme

Scheme sequence	1	2	3	4	5	6	7	Duration /d	Cost/ten thousand yuan	quality
1	1	2	1	2	1	2	1	810	15298.18	79.75
2	1	2	1	2	2	2	2	820	14992.88	78.25
3	1	2	2	1	1	1	2	820	16321.18	82.36
4	2	1	1	1	2	2	1	816	16536.21	81.25
5	1	2	2	2	2	1	2	807	15362.12	79.65
6	2	1	1	1	1	2	1	808	16204.74	80.25
7	1	1	1	1	2	1	2	807	1501.27	78.12

From Table 2, it can be seen that there are 7 construction process combination schemes after the algorithm improvement, and there are two construction process combination schemes obtained from the basic ant colony algorithm. The improved algorithm has more options for managers. After comprehensive consideration, Option 7 was selected. This group of plans has a short construction period, low cost, and high quality. If you have higher requirements for quality, you can choose option 3. The above results show that the improvement of the basic ant colony algorithm is effective and can be applied in multi-objective optimization management in engineering[8-10].

4 Conclusion

To solve the problem of multi-objective optimization in the integrated management process of engineering projects, firstly, multiple group ACO and PSO fusion algorithms are selected to study this problem. Let ants search within their respective populations, substituting the found optimal value into the particle swarm algorithm as the starting position of the particles to continue searching, and then obtain the optimal set. This approach not only avoids the problem of single population and single pheromone being unable to search for complex environments, but also solves the problem of slow convergence speed and premature maturation of ant colonies during the search process. Secondly, based on the simulation of the basic ant colony algorithm and the fused algorithm under the conditions of MATLAB, it was found that the method proposed in this paper can run multiple sets of optimal solutions, and it has been proven that the three can achieve common optimization within a certain range, without sacrificing one goal to optimize the other two goals. This demonstrates the effectiveness and applicability of the algorithm.

References

1. Dong, Z., & Chen, X. (2021). Multi objective optimization design of building construction period based on bim and genetic algorithm. Journal of Physics: Conference Series, 1992(2), 022184-.
2. Saad, D. A., Masoud, M., & Osman, H. (2021). Multi-objective optimization of lean-based repetitive scheduling using batch and pull production. Automation in Construction, 127(103696).
3. An, Y., Wang, J., Lu, H., & Zhao, W. (2021). Research of a combined wind speed model based on multi-objective ant lion optimization algorithm. International Transactions on Electrical Energy Systems74(12), 31.
4. Akehashi, H., & Takewaki, I. (2021). Modeling of resilience based on categorized recovery scenario and improving resilience with viscous damper. Journal of Structural and Construction Engineering (Transactions of AIJ), 86(782), 577-588.
5. Wang, Y. X. H. (2021). Tunneling parameters optimization based on multi-objective differential evolution algorithm. Soft computing: A fusion of foundations, methodologies and applications, 25(5)74.
6. Chen, X., Xiao, C., Shi, H., & Hong, F. (2022). Research on site selection of changsha–zhuzhou–xiangtan railway logistics center based on grey wolf optimization algorithm. Journal of Uncertain Systems, 15(02)74.
7. Dang, H. A., Dinh, V. B., Tong, M. Q., Nguyen, T. K., Nguyen, H. H., & Nguyen, D. Q., et al. (2022). A simulation-based multi-objective genetic optimization framework for efficient building design in early stages: application for vietnam's hot and humid climates. International Journal of Building Pathology and Adaptation, 40(3), 305-326.
8. Li, Y., Zhang, Z., & Xu, L. (2022). Multi-objective structural optimization of the aluminum alloy subway car body based on an approximate proxy model. Advances in Mechanical Engineering, 14(5), 193-202.
9. Liu, Y., Cheng, H., & Liu, C. (2022). Optimization of construction program schedule plans based on multi-objective optimization theory. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 46(6), 4763-4782.
10. Zhang, Q. (2021). Research on the construction schedule and cost optimization of grid structure based on bim and genetic algorithm. Journal of Physics: Conference Series, 1744(2), 022065 (5pp).