Construction Time-Cost Optimization of River Dredging Project in Cold Region Based on NSGA-II Algorithm

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Abstract. The construction of water conservancy projects is increasingly restricted by non-technical factors such as climate, environment and society, so it is particularly important to optimize it to improve the benefits of construction enterprises. Taking a river dredging project in cold region as an example, this paper uses NSGA-II algorithm to carry out multi-objective optimization of the construction time-cost, and uses MATLAB software to compile the construction optimization program of dredging project. Finally, the optimal combination of construction time and cost is obtained. The results show that the optimization results are in line with the actual situation of the project and save about 10% of the investment for the project. The method in this paper can provide useful reference for the optimization control of the construction progress of the actual project.

1. Introduction

In recent years, with the state’s attention to environmental governance, the comprehensive regulation projects for river have gradually increased. The comprehensive regulation project for river involves many fields such as water conservancy, water transportation, environment, ecology and urban landscape, which has the characteristics of large scale, large investment, wide coverage, many processes, long period and complex technology, and is also affected by non-technical factors, such as local climate, construction environment and society. How to control these uncertainties, scientifically and reasonably formulate construction schedule, allocate funds, and arrange machinery and personnel becomes the key to enhance the benefits of construction projects.

The optimization of construction time and cost is mainly to obtain the optimal solution under limited constraints by establishing an optimization mathematical model. The time-cost optimization of the comprehensive regulation project construction for river belongs to multi-objective combination optimization problem. While ensuring the sustainable operation of the project and the safe and orderly construction of each process, it achieves the shortest construction time and the best cost, and achieves the purpose of improving the economic benefits of construction enterprises.

With the development of optimization algorithm and computer technology, the multi-objective optimization control theory based on mathematical model, especially the genetic algorithm, has been widely used in large-scale construction projects for its fast calculation speed and the characteristic of easy to obtain the optimal solution. Hu Liangming et al.[1] optimized the rural water supply network based on genetic algorithm. You Jian[2] proposed a dam safety evaluation model based on improved genetic algorithm to solve the limitation of traditional comprehensive evaluation index algorithm for dam safety. Taking a practical water conservancy project as the research object, Li Bin[3] used multi-objective optimization genetic algorithm to optimize the construction time, cost and quality of the...
project, and verified the feasibility of the application of the algorithm in the optimization of the actual construction schedule of the project. Li Jingke et al. [4] established the objective functions of multi-objective construction progress from three aspects of minimum investment, shortest construction time and best quality. The simulation of a practical project further verified that the multi-objective genetic algorithm can better solve the optimal solution of the objective function of construction progress, and can provide a variety of optimization schemes. Ruan Hongbo[5] constructed a three-dimensional multi-objective optimization mathematical model of project time-cost-quality on the basis of quantifying quality, and solved it with multi-objective genetic algorithm NSGA-II. Liu Donghai et al. [6], taking a high core-wall rockfill dam as an example, used genetic harmony algorithm to optimize its construction schedule comprehensively, thus realizing the balanced arrangement of engineering quality, safety and construction progress. Zhong Denghua’s academician team[7] established the mathematical model of construction time, cost and quality, optimized the face rockfill dam project, allocated resources reasonably, and provided reference for the project builder. Considering the whole construction project, Guan Hongyan[8] took the balance, optimization and decision-making of three objectives of construction time, cost and quality of water conservancy project construction as the research objects, and put forward the large model and decision-making method of the balanced optimization of the three major objectives.

Based on the above analysis, this paper applies the improved GA algorithm to the example of river dredging project. By introducing NSGA-II algorithm, the multi-objective optimization of construction time-cost and the scheme optimization are carried out. The application of the example shows that the method is effective and reasonable, which can provide some guidance and reference for the optimization control of the construction schedule of the actual project.

2. Establishment of Mathematical Optimizing Model of Construction Time-Cost

2.1. Overview of Optimization Principles
The main task of comprehensive optimization of construction schedule-quality-cost of river dredging project is to find the best project schedule, so as to make the construction quality as high as possible, the construction progress as fast as possible, and the cost as low as possible. Taking the shortest construction time and the lowest cost of river dredging as the optimization objective, the mathematical model based on multi-objective optimization is established with the upper and lower limits of the duration and cost of each process as constraints, and the multi-objective genetic algorithm NSGA-II is used to solve the problem, so as to realize the optimization of the construction time-cost of river dredging project.

2.2. Objective Function
Taking the shortest dredging construction period and the lowest cost as the optimization objective, the following objective functions are constructed:

\[
\min T = \sum_{i=1}^{K} \sum_{k=1}^{X} x_{ik} E[d_i]
\]  \hspace{1cm} (1)

\[
\min C = \sum_{i=1}^{K} \sum_{k=1}^{X} x_{ik} E[C_i] + T \times C_d
\]  \hspace{1cm} (2)

In the equations, \( T \) is the optimized construction period; \( C \) is the optimized cost; \( i \) is the construction procedure; \( k \) is the option of each process; \( x_{ik} \) is 0-1 binary decision variables; \( d_i \) is the hour of work of \( i \); \( C_d \) is the indirect cost.
2.3. Constraint Condition
With the upper and lower limits of the duration and cost of each process as constraints, the following constraint equations are established:

\[
\begin{align*}
    \text{s.t.} \quad & \sum_{k=1}^{K} x_{ik} = 1 \\
    & E[t_i] - E[d_i] \leq E[t_j] \\
    & E[d_i] \in [d_{i_{min}}, d_{i_{max}}] \\
    & E[t_i] + \sum_{k=1}^{K} x_{ik} E[d_i] \leq E[t_j] \\
    & E[C_i] \in [C_{i_{min}}, C_{i_{max}}] \\
\end{align*}
\]

In the equation, \(i\) is the construction procedure; \(k\) is the option of each process; \(K\) is the number of total schemes; \(x_{ik}\) is 0-1 binary decision variables; \(J^\dagger\) is the successor work of \(i\); \(t_i\) is the starting time of work \(i\); \(t_j\) is the starting time of \(J^\dagger\); \(IC\) is the indirect cost; \(d_i\) is the working time of \(i\); \(B\) is the cost budget.

3. NSGA-II Algorithm

3.1. Algorithmic Principle
NSGA-II algorithm has been widely applied to solve multi-objective optimization problems in various fields of engineering since it was proposed by Deb K et al. [9] in 2000. It adds non-dominant sorting based on the genetic algorithm achieving crossover and mutation selection to retain good individuals in the population, uses fitness function to maintain the diversity of the population’s parents and minimize the number of objective functions. The core of the algorithm is to coordinate the relationship between the various objective functions and find the optimal solution set to make each objective function achieve the desired value as far as possible.

3.2. Algorithm Design
According to the objective function and constraints described in the previous section, operators are usually designed for multi-objective optimization problems of time-cost. The combination schemes are mostly non-dominated solutions, so the use of non-dominated sorting method in the whole process of the algorithm greatly reduces the computational efficiency, and is not conducive to the convergence of the algorithm. In this paper, based on the traditional genetic algorithm, fast non-dominated sorting and congestion calculation are carried out to improve the computational efficiency, accelerate the convergence speed and improve robustness of the algorithm. At the same time, elite strategy operator is introduced to ensure the stability of the calculation results.

The flow chart of NSGA-II algorithm is shown in Figure 1. gen is an evolutionary algebra and \(N\) is the population number.
4. Engineering examples

Taking the dredging construction from Sihua Sluice to Yijianpu of Yitong River in Changchun City as an example, this paper uses NSGA-II algorithm to optimize the construction time-cost. The project is constructed by dry dredging method, and the construction procedure is simplified as follows: (1) construction preparation, (2) construction of longitudinal cofferdam, (3) construction of transverse cofferdam, (4) drainage diversion, (5) silt excavation and transportation, (6) sediment treatment for outward transportation and disposal, (7) project acceptance, transverse cofferdam demolition and other procedures. The project has a dredging capacity of 1.86 million m³, a dredging length of 5.5 km, a water area of 1.54 million m², a dredging depth of about 1.2 m above the water conservancy elevation, a total planned construction period of 365 days, a planned investment of 60 million yuan, and an indirect cost of 1,000 yuan per day. The parameters and data of the dredging construction scheme are shown in Table 1.

The NSGA-II algorithm, based on the traditional genetic algorithm, uses the non-dominant sorting operator, crowding operator and elite strategy selection operator described in the previous section to screen each process in dredging construction, and iterates continuously in the search space, so as to obtain the optimal solution combination. The parameters of the algorithm are as follows: population number N=80, evolutinal generation gen is 50, mutation probability Pe=0.05, crossover probability Pc=0.7, and number of functions n=2.

| Construction procedure | Schemes (duration d/day, cost c/10,000 yuan) |
|------------------------|---------------------------------------------|
|                        | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 |
| d | c | d | c | d | c | d | c | d | c | d | c |
| 1 | 18 | 150 | 17 | 168 | 16 | 173 | 15 | 179 | 14 | 189 |
| 2 | 68 | 1140 | 60 | 1200 | 58 | 1350 | 54 | 1526 | 50 | 1720 |
| 3 | 85 | 1344 | 82 | 1452 | 78 | 1523 | 72 | 1586 | 69 | 1689 |
| 4 | 20 | 4 | 16 | 4.8 | 15 | 5.6 | 13 | 6.3 | 12 | 7.4 |
| 5 | 150 | 2490 | 155 | 2313 | 145 | 2566 | 135 | 2400 | 130 | 2365 |
| 6 | 70 | 150 | 65 | 168 | 57 | 173 | 55 | 186 | 50 | 200 |
4.1. Optimization Results
Based on the data listed in Table 1, the related algorithm program of NSGA-II is compiled by using MATLAB software. The final optimization results are shown in Figure 2-Figure 4, and the results of satisfactory solution of comprehensive optimization of construction time-cost are shown in Table 2.

From the results of the time-iteration curve obtained from the optimization calculation of NSGA-II algorithm, it can be seen that under the condition of balanced resource allocation, the construction time tends to be stable with the increase of iteration times, which shows that the algorithm can search the minimum of the construction time.

From the trade-off chart of construction time-cost, it can be seen that there is an inverse ratio between construction time and cost, and shorter construction time will lead to increased cost, which is the same as previous research conclusions and conforms to the actual project. The validity and feasibility of the application of NSGA-II algorithm to the dredging project of Yitong River are verified by an engineering example. According to the search efficiency, there are 56 feasible solutions in the search space. The NSGA-II algorithm reduces the computational complexity and runs efficiently. The optimal solution is 313 days, which saves 52 days compared with the planned time. The optimized cost is 52.31 million yuan and saves 10% of the cost. Thus, it can be

| Number | Duration (days) | Cost (10,000 yuan) |
|--------|----------------|--------------------|
| 1      | 321            | 5265               |
| 2      | 313            | 5232               |
| 3      | 316            | 5245               |
| 4      | 317            | 5268               |

Figure 3 and Figure 4 are respectively the construction time-cost trade-off chart and work Gantt chart optimized by multi-objective algorithm. From the trade-off chart of construction time-cost, it can be seen that there is an inverse ratio between construction time and cost, and shorter construction time will lead to increased cost, which is the same as previous research conclusions and conforms to the actual project. The validity and feasibility of the application of NSGA-II algorithm to the dredging project of Yitong River are verified by an engineering example. According to the search efficiency, there are 56 feasible solutions in the search space. The NSGA-II algorithm reduces the computational complexity and runs efficiently. The optimal solution is 313 days, which saves 52 days compared with the planned time. The optimized cost is 52.31 million yuan and saves 10% of the cost. Thus, it can be
seen that using NSGA-II algorithm to solve the multi-objective optimization of time-cost of river dredging project has considerable economic benefits and practicability. In addition, the corresponding work Gantt chart can be obtained by using NSGA-II algorithm, which enriches the calculation results.

5. Conclusions
In this paper, the NSGA-II algorithm is applied to the optimization of the construction time and cost of river dredging. The optimization results are in line with the engineering reality, and can solve the optimization problem of the construction time and cost. The application of NSGA-II algorithm improves the efficiency, and also verifies the rationality and operability of the optimization model of time-cost tradeoff, which can provide theoretical basis and better guidance for practical engineering.

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