Optimization Model Calculation of Construction Cost and Time Based on Genetic Algorithm

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Abstracts. In the process of multi-objective problems, traditional algorithms have certain defects, especially because of the increasing number of conflicts and the increasingly complex application environment. This paper proposes a practical method to solve the multi-objective optimization problem for the duration and cost requirements in the construction project management, in order to reduce the error probability that the optimized project will produce in the actual project. Different from the existing optimization methods, this design modifies the curve of the time cost, and improves the parameters of the traditional genetic algorithm design and operation process design, which greatly increases the degree of fitness between the algorithm and the actual project. The model is based on genetic algorithms and combines different algorithms, so a simple and excellent Pareto solution can be quickly obtained. At the same time, optimization and simulation are carried out in an orderly way during the construction period. This new method is reasonable and effective in the very complicated multi-objective optimization problem of managing construction period and cost through an engineering example.

1. Introduction
The project management is usually required to satisfy the requirements of quality and function of one project as plan within the budget limit of duration and cost, so as to achieve high economic and social benefits. The successful operation of the project requires coordination and cooperation in all aspects of which the operation will be participated by the personnel, mechanical equipment and material resources of different industries [1]. During the process of the coordination requirements, the conflict relationship is a great problem for the project manager. There is an inevitable phenomenon: the shortening of the construction period will inevitably lead to the increasing of the cost, and the cost reduction within a certain scope will inevitably extend project duration [2-4]. The enhanced considerations and trade-offs are needed to determine the ultimate optimal project management solution that minimizes project duration and minimizes the cost of the project [5]. For cost optimization problems, these solutions are achieved by sacrificing a certain number of goals in order to achieve overall gain or meet a specific demand. In simple terms, this is a solution that can be achieved by rationally allocating resources, appropriately increasing (reducing) the construction costs...
of sub-projects, and compressing (relaxing) project activity times. It is the optimal combination of subitems that a program or algorithm can find within a certain period of time or cost.

It’s a fact that there will be multiple competing goals and multiple different functional solutions before the implementation of the project. The decision maker of the project must choose a feasible program that is conformed to the engineering characteristics to hold the program. As the scale of construction projects expands, the complexity of calculations will increase exponentially. The traditional enumeration method and the key path method of network map planning and other methods are difficult to meet the current needs of computing. In this context, the heuristic algorithm is gradually used as the main tool to solve this problem [6]. Although in the past research, more complex solutions such as ant colony algorithm, particle swarm algorithm, simulated annealing algorithm, and logic have been studied. From the perspective of design capabilities and application effects, genetic algorithm (GA) is undoubtedly the best among many solutions, and this view has been proved [7]. GA is an artificial intelligence algorithm. It is based on the concept and theory of bionics. It imitates the structure and function of organisms and solves such combinatorial optimization problems. Feng first proposed the use of genetic algorithms to optimize the direct cost of generating the best individuals; F. Farshi Jalali and F. Shirvani[2] improved the existing GA model and expected to avoid the local Pareto solution optimization; Ozcan-Deniz[8] considered the influence of environmental factors on algorithmic operations and results in non-dominated sorting genetic algorithm design; Marzouk and Moselhi[9] applied genetic algorithm to the discrete construction period of earthwork project-cost-quality optimization problem; Zhenyu Zhao et al. [10] improved the design of the structure matrix and genetic algorithm, focusing on the optimization of concurrent engineering in large projects.

There are two difficulties in optimizing the project. First, because of the unavoidable nature of the competition objectives and the mutual influence among various goals, it is very complicated to find an accurate Pareto solution front. Second, finding the best trade-offs in the optimal set of Pareto solutions is also a major challenge. Under this circumstance, this paper improves the design of genetic algorithm and establishes a new duration/cost optimization model. It can intelligently find the Pareto solution as few as possible, and provide decision-makers with more realistic and reliable multi-objective problems.

2. Target Description and Data Modeling

The total construction period of the project is summarized by the time of each sub-procedure, while, the sub-processes require no free-run and non-parallel processes. That is, after the previous work, the latter work can and must begin immediately without the restriction of resources or other process procedures. The selection of time parameters of each process should meet the constraints of the logical relationship between the processes. Therefore, the optimization model of the construction period is as follows: 

\[ T = \sum_{i=1}^{n} \min\{D(i,1), D(i,2), \ldots, D(i,n)\} \]

A project is made up of \( i \) sub-processes, and the project manager will have \( j \) plans to select for each activity. In the optimization scheme, the duration of each process needs to meet the requirements of the shortest duration of the process, and should not be greater than the normal working time. The total construction period shall not exceed the time limit specified by the owner or contractor.

The cost composition of the project is divided into two parts: one is the direct cost, including labor cost, machinery and materials. The other is the indirect costs, including some stipulated fees, project management fees, etc. In order to improve the practicability and universality of the optimization scheme, the paper is to fit the relationship between duration and cost into the following linear function (Figure. 1) to optimize the calculation.
Figure 1. The objective function of duration and cost optimization based on.

The corresponding cost increase and decrease can be found according to the formula:

\[ C = \min \sum \left[ F_{D(i)} + \Delta F_{D(i)} + \Delta D(i) \right] \]

Among them:

\[ F(D(i)) = \left[ C(D^1(i)) - C(D^0(i)) \right] / \left[ (D^1(i))^2 - (D^0(i))^2 \right] \times (D(i))^2 \]

\[ + \gamma \left[ C(D^3(i)) - C(D^2(i)) \right] / \left[ (D^2(i))^2 - (D^3(i))^2 \right] \times (D(i))^2 \]

While, the total cost obtained after optimization should be lower than the maximum value of the estimation of contract.

3. The solution and analysis of the model

The genetic algorithm is widely used with the powerful global search strategy and adaptive random search function. It is modeled after the evolutionary selection of nature's creatures. In the continuous searching process of an individual, the individual is selected or modified or disappeared according to the deviation distance, therefore, the randomly generated population is getting closer to the optimal Pareto solution. Due to the different requirements of various application environments, the genetic algorithm can change the objective function, so as to guide the search direction and change the parameter setting to control the convergence rate, and ultimately to get a good adaptive goal. The optimization model for this design is based on genetic algorithms and involves multi-target selection theory and project management theory. In order to combine the content and parameters organically, the model needs to rely on computer implementation, especially the evolutionary iterative process of genetic algorithm.

3.1. Coding and chromosome design

In the MATLAB environment, a floating-point encoding is chosen from a variety of encoding methods, such as binary string encoding, floating-point encoding, general data encoding and permutation encoding. In this way, the topological structure of the genotype is consistent with that of the phenotype, while, the optimal parameter value in the chromosome is the last Pareto solution. In simple terms, genotype and phenotype are easy to switch. During the operation, the time of encoding and decoding is saved, so that the program running time is not subject to more processes and constraints. The most important point is that the real number of coding is not easy to produce the Hamming cliff; and the two individuals never show great differences in the process of cross mutation only when a certain point is changed. According to the logical relation identified in the double code network diagram, the process is sorted through the activity process. The combination of each possible process is constructed into one chromosome, of which are arranged in the order of genes.

3.2. Fitness function design

The fitness function is the only criterion for searching for evolution in genetic algorithms. Meanwhile, it can determine the speed of convergence. If the fitness function is simple, the time for the program to evaluate the ranking will be short. On the contrary, the more complex of the fitness function is, the more difficult the search evolution is and the longer the time it takes. Therefore, in the design of the most simplified fitness function, the objective function of the project duration nd the cost of objective function is as the fitness function. However, as the fitness function is the highest point of evaluation, and due to the consideration of matching objective function, the fitness function needs to be modified as the follows: 

\[ \text{Fit}(i) = 1 / C_i \]
3.3. Genetic mechanism design
The genetic mechanism of the population mainly consists of three parts of selection, crossover and mutation, and iteration. Among them, a) the selection is: Using roulette selection strategy for random selection, the roulette wheel is composed of the whole chromosomes. A random rotation of the wheel, the pointer to the sector of the chromosome will be selected. If the fitness function of the individual is large, the area of the chromosome in the sector will be large too, and the corresponding probability being selected will be large. Rotating the wheel for multiple times will result in the generation of a new generation. Note: the selection is random. In order to avoid the best individual loss in the process of random selection, the optimal ordered individual enters directly into the next cycle. b) The crossover and mutation: some chromosomes in population obtained the progeny chromosomes by crossover probability, and the new chromosomes were obtained by real-valued mutation of the mutation probability. It is worth noting that the process of selection, crossover and mutation need to keep the total population capacity unchanged. c) Mutation: The iterative process of genetic algorithm is the cyclic process of the finite number of algorithm procedures, and the specific process of the program is shown in Figure 2. The first cycle starts with initializing the population. And the population size will affect the accuracy of the running time of program, as well as the final result.

Figure 2. Program flow chart

Figure 3. Network construction drawing of the overall project.

4. Numerical example
There is an actual construction network plan of civil engineering projects to be constructed (Figure 3). Through the investigation and analysis of the contract documents, the normal working period and normal cost of the contract plan are obtained. The basic engineering construction of the project was selected to optimize the analysis, and the data was shown in Table 1. If the normal construction of the project is completed, the completion time of the project will be 87 days, with the required cost of RMB 3,157,000, while, if it is under emergency construction, the project will take 53 days to complete with the cost of 42.35 million yuan.

| No. | Activity                  | Normal duration | Emergency duration | Normal cost | Emergency costs |
|-----|---------------------------|-----------------|--------------------|-------------|-----------------|
| 1   | Precipitation             | 15              | 9                  | 30          | 57              |
| 2   | Earth Excavation          | 7               | 4                  | 20          | 35.5            |
| 3   | Slope Shoring             | 5               | 3                  | 50          | 9.5             |
| 4   | Construction of Mattress  | 3               | 2                  | 3           | 5.4             |
| 5   | Construction of Guide Wall| 2               | 1                  | 2           | 3.6             |
| 6   | Waterproof Construction   | 3               | 2                  | 4           | 5.4             |
| 7   | Foundation Reinforcement  | 15              | 10                 | 150         | 170             |
| 8   | Basic Template            | 3               | 2                  | 3           | 4.8             |
9 Basic Concrete 4 2 40 50
10 Wall Column Reinforcement 8 5 10 17
11 Wall Column Plate Template 18 11 25 40
12 Girder Steel Binding. 2 1 5 7
13 Concrete Pouring 2 1 10 13

To set the program parameters: the cross probability and the mutation probability are 0.8 and 0.2, and the population size N is 150. The running results of the program are shown as follows: 1) When the construction duration needs to be compressed by x days or reduced the cost by y Yuan, the cost or the period will gradually tend to a stable value as the number of iterations increases. And with the increase of iteration times, the value remains the same (Figure 4-5). For example, when the duration of the project is reduced to 70 days, the planned cost will gradually tend to be stable at 35,4862 million yuan, and the time spent by each process will also remain unchanged (Table 2).

Table 2. Iterative Data of Genetic Algorithms

| No. | Gene. | Duration | Total duration | Total cost | Deviation (%) |
|-----|-------|----------|----------------|------------|---------------|
| 1   | 1     | 9 4 3 2 1 2 12 3 4 8 18 2 2 | 70 | 379.238 | 0.069 |
| 2   | 1000  | 9 4 3 2 1 2 12 3 4 8 18 2 2 | 70 | 379.112 | 0.068 |
| 3   | 2500  | 9.5 4.5 3 2 1 2 12 3 4 8 18 2 2 | 70 | 375.861 | 0.059 |
| 4   | 3000  | 10.5 5.5 3 2 1 2 13.5 2 4 7 16.5 1 2 | 70 | 371.912 | 0.048 |
| 5   | 3250  | 11.5 7 3 2 1 2 14.5 2 4 6 5 13.5 1 2 | 70 | 362.718 | 0.022 |
| 6   | 3500  | 12.5 7 3 2 1 2 15 2 4 6 13 1 1.5 | 70 | 358.232 | 0.009 |
| 7   | 4000  | 13 7 3 2 1 2 15 2 4 7 11 1 2 | 70 | 354.862 | 0 |
| 8   | 4500  | 13 7 3 2 1 2 15 2 4 7 11 1 2 | 70 | 354.862 | 0 |

The envelope diagram of the cost optimization results (Figure 6): a Pareto solution composed of Pareto solutions under different constraints. The Pareto solution frontier generated by genetic algorithm can help the project decision makers to choose the optimal activity combining with the flexible activity space under any constraints of time and cost so as to achieve the maximization of economic benefits and social benefits.

5. Discussion and future development

The model proposed in this paper successfully overcomes the limitations of previous designs. It has been proven to have the following outstanding contributions: (1) Providing a new solution method, which can obtain the maximum benefit of the project and its corresponding project management arrangement scheme when the cost and duration are taken as two major constraints. (2) Considering the influence of indirect costs on the relationship between project cost and duration, this paper re-describes and demonstrates the changes of period and cost. (3) Adapting the parameters such as fitness function, specifying the matching coding method and chromosome composition form, and designing and modifying the solution flow, aiming at accelerating the convergence speed and increasing the accuracy Rationality, avoid falling into a partial optimal trap; (4) The simulation of the
proposed scheme is performed. Although only a part of the project is searched and optimized, the validity of the model has been proved. The main drawback of this algorithm is that it is difficult to overcome the randomness in the search process, which may require a long processing time for large-scale projects, and there may be instability in the search results. In response to this problem, the author is currently working hard to improve.

6. Conclusions
This study aimed at the proposal of a multi-objective optimized scheme which can perfectly balance the construction period and cost. Different from the existing schemes, the scheme is to show a self-adaptive method to improve the current genetic algorithm problems in terms of the characteristics of multiple optimized objectives. It is to ensure the stability of the convergence and the science and reliability of the scheme. In addition, the calculation program will be improved to obtain the distributed Pareto solution front with a wide application prospect. Through the discrete Pareto mathematical model, the project decision maker can obtain the whole favorable data and solution. For the overall analysis, the design is to take full consideration of problems of practical engineering, such as: the large number of processes, implementation ways, and the crossover between processes. The traditional multi-objective procedure is to be improved, and the problem of mismatch between optimization result and actual construction arrangement will be changed. The application to engineering examples can also prove its feasibility. In addition, the multi-objective optimization model developed in this research can also be easily applied to other multi-target research fields with good target applications.

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