Construction Schedule Optimization Based on Genetic Algorithm

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Abstract. With the continuous growth of the global economy and the rise of information technology, construction progress has become the focus of digital analysis in the construction industry. This paper studies the optimization of digital technology in construction progress, constructs a schedule-cost optimization model, and uses genetic algorithm to assist digital technology to analyze progress optimization. Taking an apartment project as an example, the genetic algorithm is written based on Python software, and the optimized construction schedule is compiled after comprehensive analysis, which shortens the duration and reduces the cost. The full integration of big data technology and computer technology improves the calculation efficiency, realizes the intelligent management optimization of the system, provides intelligent analysis for the project progress management, sets the project progress scientifically, and provides ideas and methods for the project progress management.

Keywords: Genetic algorithm；Construction work; Digitize；Project Progress；Optimization solutions

1 Introduction

Over the past thirty years, China's construction industry has entered a golden period of vigorous development, and the continuous and stable growth of the construction industry has played an indispensable role in promoting the country's economic growth. With the deep integration of information technology and construction projects, people have put forward higher requirements for construction quality, management ability and project progress. Traditional management technology means and management mode can no longer meet the development of informationization in the construction industry, so exploring new technology and new methods with higher efficiency has become a key issue. The field of construction engineering is also in deep integration with new technologies such as big data, cloud computing, Internet of Things, blockchain, VR, AI and 5G, actively exploring and using new technologies, applying modern information means, and gradually changing to the direction of digitalization, virtualization and informatization.

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As a crucial part of the project management system, construction progress management is a guarantee for the timely completion of the project. Although the traditional progress management has been improved to a certain extent, it still has some deficiencies, and it cannot accurately realize the sharing of information, and it cannot ensure the effective coordination between the various parties involved in the project. Therefore, under the constraints of cost and other objectives, digital analysis of the construction progress, and take appropriate optimization methods to optimize the progress plan, to ensure that the progress plan to guide the construction in the best state.

In recent years domestic and foreign scholars have conducted many studies on construction schedule optimization. The foreign research development time is longer and the research is more in-depth.Hadeel et al[1]. proposed a hybrid meta-heuristic algorithm, which combines particle swarm algorithm and simulated annealing search process, and the precise optimization process reduces the computation time to optimize the project schedule.Rifat et al[2]. proposed a new hybrid optimization approach, which can obtain high-quality planning and scheduling with fewer computations for large-scale projects. Zhang Li[3] constructed a systematic theoretical and technological framework system for digital building construction by drawing on the model of advanced manufacturing and the practice of digital building engineering. Dong Wenping et al[4]. proposed a 3D visualization model of deep foundation pit and established a full-system digital simulation system. Shen Jianhong et al[5]. introduced the harmonic search algorithm into the duration-cost optimization problem, realized the duration-cost optimal solution through algorithm programming and verified its feasibility in the case. Fu Ganghui et al[6]. combined BIM[7] technology with genetic algorithm to solve the costing problem with the help of software to optimize and analyze the duration and cost. In summary, scholars at home and abroad have conducted many studies on project construction cost progress, such as intelligent analysis of project construction progress[8-10] before the start of the actual construction, scientific prognosis of the project's engineering progress information, the preparation of an implementable construction progress plan, the use of intelligent management and control technology in the construction progress, and the comprehensive optimization of the construction progress, which will provide ideas and methods for the similar project progress.

Most of the traditional construction progress management belongs to ex post facto control from the time point of view, and measures are taken to adjust the deviation only after the deviation has already occurred, which has already had an impact on the total project duration, and the cycle of analyzing and adjusting the deviation is longer, and even if measures are taken to make up for the deviation, the cost will also be increased. This paper is based on digital technology to analyze and optimize the construction progress, using intelligent algorithms to analyze the progress data, constructing the "duration-cost" optimization model, using genetic algorithms to solve the problem, and obtaining the optimized duration of each construction process and the optimized cost of the lowest case of the corresponding duration. The optimized duration of each construction process and the corresponding construction period with the lowest cost after optimization are solved by genetic algorithm.

The use of big data and Internet of Things technology to carry out intelligent control of the engineering site, promote the refined development of engineering projects, and

create a "smart site" construction. Through real-time monitoring of the construction site, data collection, intelligent optimization algorithms, as shown in Fig. 1, intelligent management in the context of the current industry 4.0 era, the use of a variety of technical means to promote the effective implementation of the progress of the project.

2 Construction Schedule Optimization Based on Genetic Algorithm

The scientific formulation of construction progress plan is the premise of the smooth implementation of engineering construction projects. After the initial preparation of the completed progress plan, although the duration and relationship of each process has been determined, it is also necessary to take the cost factor into account, and comprehensively consider the progress-related indicators to make further optimization of the project progress. Genetic algorithm is a kind of intelligent optimization method, which is formed by referring to the evolution and inheritance of species in nature, simulating the selection, crossover and mutation occurring in the process of heredity and evolution of organisms, and establishing mathematical model for the problem in order to complete the process of adaptive search for the optimal solution of the problem. As a global optimization search algorithm, genetic algorithm is simple and easy to use, and it can solve the optimization problem more easily and satisfactorily, and it is widely used in various optimization problems and models such as artificial intelligence.

Constructing the construction schedule optimization model needs to take the rationality of construction resources, the calculability of the key lines of the schedule and the stability of the construction environment into consideration, so the following assumptions are put forward: (1) After adjusting the duration of the work, the key work and the non-critical work will not be transformed into each other, the duration of each work is greater than or equal to the limiting time and is less than or equal to the normal time, and the direct cost incurred by the various jobs is between the normal cost and the limiting cost; (2) for the construction tasks that have already started, there can be no interruption; (3) there is no shortage of resources affecting the construction progress; (4) the direct cost shows a non-linear relationship with time, and the overhead rate is a fixed value; (5) the influence of the construction environment, technology, and management level on the construction progress is ignored; (6) If there is a construction process that has more than one pre-process, it should be ensured that the pre-processes do not affect each other, and that failure to complete a pre-process in accordance with the requirements will have an impact on the subsequent process. Adopting increased resource inputs and new technologies and methods to shorten process duration is accompanied by an increase in direct costs. The more the process is compressed, the faster the direct costs will increase due to increased labor and machinery costs.

The quadratic expression of the relationship between the duration of a construction process t_i and its direct cost C_{Zi} proposed by Richard et al. is borrowed here in the following equation, where C_{Zi}-direct cost of process i, t_{ni}-normal duration of process i, t_{si} -direct cost of process i at the shortest duration, Cni -direct cost of process i at the normal duration, and αi-increase in the rate of increase in the direct cost of process i.

$$C_{Zi}=C_{ni}+\alpha\left(t_{ni}-t_i\right)^2 \tag{1}$$

$$\alpha_i=\frac{\left(C_{si}-C_{ni}\right)}{\left(t_{ni}-t_{si}\right)^2} \tag{2}$$

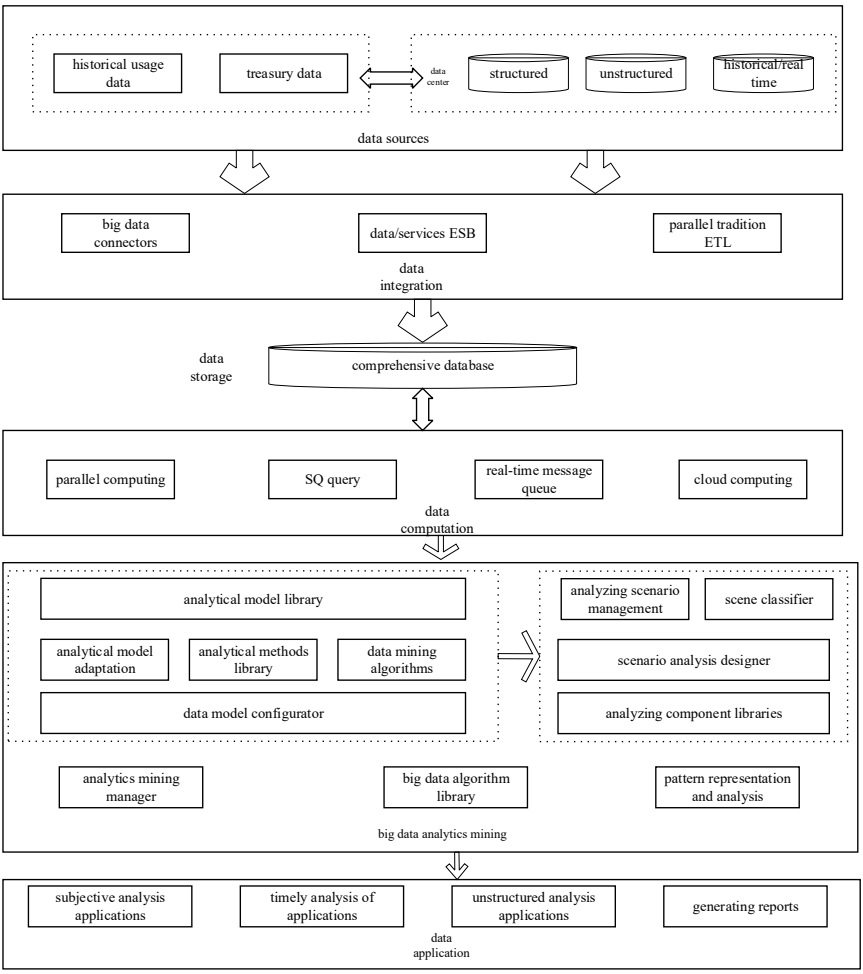

Fig. 1. Digital Intelligent Engineering Management

Indirect cost is positively correlated linearly with the duration, the longer the duration, the higher the indirect cost. Therefore, in this model, only the case of early completion of construction is considered, and the functional relationship between the change indirect cost C_{JX} and the duration is established as follows: T - the actual duration of the project, T_R - the contract duration of the project, γ - the incentive cost of the project completed one day ahead of schedule, β - the Project indirect cost rate.

$$C_{JX}=T\beta-\left(T_R-T\right)\gamma \tag{3}$$

In summary, the establishment of the total cost of the minimum as the objective function of the duration - cost mathematical optimization model, expressed in the following formula, where C - calculated cost of the project; C_P - contractual cost plan maximum; C_Z - project direct cost.

$$\text{MinC}=\text{Min}\left(\text{C}_\text{Z}+\text{C}_\text{JX}\right)=\sum_{\text{i=1}}^{\text{n}}\text{C}_\text{Zi}+\text{C}_\text{JX}=\sum_{\text{i=1}}^{n}\left[C_{ni}+\alpha_i\left(t_{ni}-t_i\right)^2\right]+C_{JX} \quad (4)$$

As a superior global search intelligent optimization algorithm, genetic algorithm is widely used in construction schedule optimization of building projects. The solution flow based on genetic algorithm is shown in Fig.2.

This paper is based on the specific steps of the genetic algorithm optimization model: (1) Determine the basic parameters of the optimization model regarding the genetic algorithm. Determine the initial parameters to facilitate the subsequent generation of the initial population. The initial parameters include project parameters and genetic parameters. The project parameters include: the logical relationship between the processes before and after, the total project duration T, the project indirect cost rate β, the incentive cost γ for the project to be completed one day ahead of schedule, the normal and the shortest duration t_{ni} and t_{si} of each process and the corresponding direct costs C_{ni} and C_{si}, and the maximum value of the contractual cost plan C_P; the genetic parameters include: the population size Q, the crossover probability P_c, the variance probability Pm, and the number of iterations G . (2) Generate an initial population. An initial population that satisfies certain constraints and solves the set space needs to be generated for the subsequent optimal solution search of the genetic algorithm. In this study, an initial population is randomly generated under the premise of satisfying the constraints $t_{si}\leq t_i\leq t_{mi}$ and $C\leq C_p$. The chromosome is used as a carrier of decision variables, and the real number coding method is used to encode the chromosomes, each chromosome represents the actual duration of each construction process, and each process is equivalent to a gene unit, which is constructed as a chromosome from the duration of a certain achievable activity scenario. As shown in the Fig.3, the gene position n of the chromosome represents the construction process, and the gene value t_n represents the duration of the nth process. n - gene position, t_n - gene value.

(3) Calculate individual fitness. It is a prerequisite in the genetic algorithm to determine whether the chromosomes conform to genetic selection. Usually, the larger the fitness value, the better, generally can be used directly to calculate the fitness value of the objective function, the goal is to find the minimum value of the cost, so it is necessary to make a mapping transformation of the value domain of the objective function, which can be expressed in the following formula: where: fitness (x) - fitness function; f (x) - function value of the individual x; M- for a sufficiently large value.

$$fitness\left(x\right)=M-f\left(x\right) \quad (5)$$

(4) Genetic operator operation. First of all, a merit selection of individuals, according to the value of individual fitness to introduce the probability of individual selection, the use of roulette to select the best individuals in the population, the selected individuals directly inherited to the next generation, to obtain a new population. Crossover operation is that two individuals from two parents exchange some of their genes with a cer-

tain crossover probability to form a new offspring chromosome, and the crossover probability is taken as 0.8. Mutation operation refers to the mutation of genes on the chromosome, which may be one gene or multiple genes, leading to changes in the chromosome structure, thus generating new individuals, and it is an auxiliary way of generating new individuals, and the probability of mutation generally depends on the length of chromosome and the size of population, and it is taken as 0.08 here. size, here take 0.08.

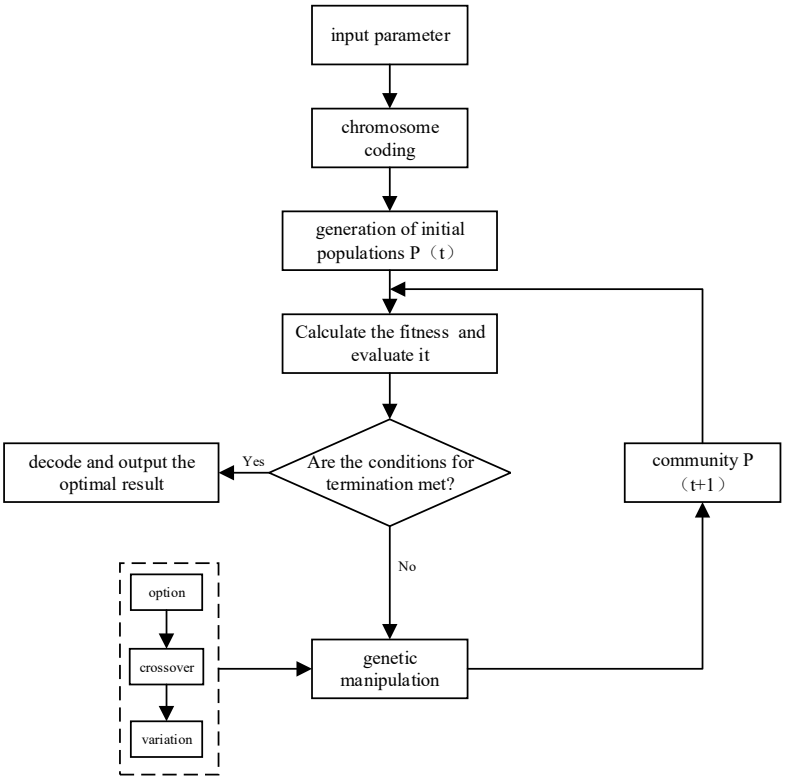

Fig. 2. Workflow of the genetic algorithm

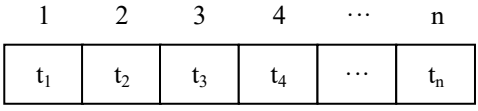

Fig. 3. Chromosome structure

(5) Iterate and output the results. The genetic algorithm solving process is an optimization process through a certain number of iteration cycles, so that the individual is gradually close to the optimal state. At the same time, it is necessary to set a reasonable algorithm to terminate the iteration, this paper adopts a certain number of iterations to terminate the genetic algorithm algorithm, the number of iterations is taken as 300. after

the above genetic algorithm solution process, decode the chromosome, arrive at the optimal solution of the target optimization model, and output the optimized time parameters of the various construction processes, the total construction period and construction cost.

3 A Condominium Project Case

This project is a staff duty apartment project, the construction site for the east side of the comprehensive security building, the south side of the sewage treatment plant, the north side of the staff activity center. The apartment consists of two "L" shaped buildings connecting Area A and Area B. The main purpose of the apartment is to provide a resting place for the staff on duty within the company, and at the same time, it also has the function of a dormitory. The structure type of the project is frame structure, the seismic intensity is seven degrees, the seismic measures are seven degrees, the reasonable service life of the structural design is 50 years, the fire-resistance level is two, and the waterproofing level of the roof is grade I. The project is a multi-storey building, and the building has the following features. The project is a multi-storey building, the number of floors is 7, the total construction area is 19529.98m^2, of which the construction area of area A is 10271.20m^2, the construction area of area B is 9258.78m^2, and the building height is 23.55m. The optimization of the progress plan can be considered from the two aspects of cost and resources, respectively, to establish the duration - cost mathematical optimization model. A staff apartment project contract is planned to start on June 13, 2023, time constraints, limited funds for the project construction of the outstanding problems faced, under the premise of ensuring quality and safety, for the project to use the duration - cost optimization model, in the construction stage of the preparatory phase of the use of genetic algorithms on the duration - cost optimization model for analysis In the construction preparation stage, the genetic algorithm is used to analyze the schedule-cost optimization model, and to seek the optimal schedule at the lowest possible cost to achieve the desired schedule optimization results. The relevant parameter values of each process are collated (two decimal places are reserved for the values of C_{ni} and C_{si}), and the schedule-cost optimization is carried out for the processes of an apartment project, and the relevant parameter values of the schedules of each process are shown in Table 1.

Table 1. Parameters related to the duration-cost optimization of a staff apartment project

Serial number	Process name	t_{ni}(day)	C_{ni}(ten thousand dollars)	t_{si}(day)	C_{si}(ten thousand dollars)
1	Construction preparation	25	6.8	20	8.1
2	Earthmoving and pit support	23	22	18	29.2
3	Foundation bedding and waterproofing and protection layer	15	10.6	12	13.2

4	Infrastructure construction	25	89.2	18	97
5	earthwork backfill	10	7	10	7
6	First floor main construction	23	50.3	18	57.2
7	Second floor main construction	12	48.2	10	52
8	Main construction of the third floor	12	48	10	50.8
9	Main construction on the fourth floor	12	48	10	50.8
10	Main construction on the fifth floor	12	44.8	10	50.8
11	Six-story main construction	12	44.3	10	47.5
12	Main construction on the seventh floor	12	44.3	10	47.1
13	First floor masonry construction	20	7.3	14	14.2
14	Second floor masonry construction	15	34.1	12	37.5
15	Three-story masonry construction	10	31.7	8	34
16	Four-story masonry construction	10	31.6	8	33.9
17	Five-story masonry construction	10	31.6	8	33.9
18	Six-story masonry construction	10	31.7	8	33.9
19	Seven-story masonry construction	10	31.7	8	33.9
20	Roofing	30	46.6	26	51.8
21	Ceiling and interior wall plastering	35	129.9	32	133.1
22	Ground floor works	35	136.2	28	143
23	Outdoor wall construction	35	138.1	30	144
24	Doors and windows installation	25	158.6	22	162.2
25	Interior wall and ceiling construction	30	265.8	26	269.5
26	completion and acceptance	7	3.8	7	3.8

Combined with the previous description of the genetic algorithm optimization method, based on the Python language on a staff apartment project duration - cost optimization to write a solution program, set the genetic algorithm parameters, the duration of each process t_i as a decision variable, take the population size of 100, the number of population iterations is 300, the crossover probability of 0.8, the probability of variance is 0.08, based on the The construction schedule is optimized based on the duration-

cost mathematical optimization model that has been constructed in this chapter. By running the main program to solve the optimization model of this project, the number of iterations of the genetic algorithm tends to be balanced when it reaches 100 generations of the population until the end of the program at the 300th generation, and the optimal solution is output. After solving the duration-cost optimization model by genetic algorithm, the optimal duration of each process is output, as shown in Table 2.

Table 2. Optimal solutions for genetic algorithms

Decision variables t_i(day)
24 22 13 24 10 23 11 11 11 11 11 12 16 14 10 9 9 9 8 29 34 31 34 24 29 7

According to the relationship between duration and the rate of increase of direct cost, the value of direct cost corresponding to each process is calculated, and the direct cost corresponding to the optimal duration of each process is calculated and organized, and the direct cost C_Z of the subsequent works is calculated, as shown in Table 3.

Table 3. Optimized process duration and corresponding costs

Serial number	Process name	Optimal duration(day)	Corresponding direct costs(ten thousand dollars)
1	Construction preparation	24	6.9
2	Earthmoving and pit support	22	22.3
3	Foundation bedding and waterproofing and protection layer	13	11.7
4	Infrastructure construction	24	89.4
5	earthwork backfill	10	7
6	First floor main construction	23	50.3
7	Second floor main construction	11	49.1
8	Main construction of the third floor	11	48.7
9	Main construction on the fourth floor	11	48.7
10	Main construction on the fifth floor	11	48.7
11	Six-story main construction	11	45.5
12	Main construction on the seventh floor	12	44.3
13	First floor masonry construction	16	10.4
14	Second floor masonry construction	14	34.4
15	Three-story masonry construction	10	31.7
16	Four-story masonry construction	9	32.2
17	Five-story masonry construction	9	32.2
18	Six-story masonry construction	9	32.2
19	Seven-story masonry construction	8	34
20	Roofing	29	46.9
21	Ceiling and interior wall plastering	34	130.3
22	Ground floor works	31	138.4
23	Outdoor wall construction	34	138.3
24	Doors and windows installation	24	159
25	Interior wall and ceiling construction	29	266
26	completion and acceptance	7	3.8

Compare the total duration and cost corresponding to the schedule of a staff apartment project with the total duration and cost after optimization, and the specific comparison and optimization results are shown in Table 4.

Table 4. Optimization before and after comparison

	pre-optimization	post-optimization	value of change
durations(day)	323	305	-18
costs(ten thousand dollars)	1705.3	1649.3	-56

Through the above analysis of the duration-cost data, a mathematical model is established to optimize the construction schedule, and the duration is shortened by 18 days and the cost is reduced by 560,000 RMB before and after the optimization. The optimization reduces the duration of each construction process and the cost of the project, and at the same time facilitates the project manager to select the optimal construction plan efficiently according to the actual situation, so as to realize the optimization of the construction schedule.

4 Conclusions

With the rapid development of information technology at home and abroad, the informationization, parameterization and refinement management of the construction industry are more and more highly concerned by experts and scholars at home and abroad, however, at present, the analysis and optimization of construction progress based on digital technology is still in the development stage, and it is not generally used in the actual projects of domestic building construction. Therefore, this paper focuses on the construction preparation stage which has a greater impact on the progress in construction projects, analyzes the construction progress plan and optimizes it. Combined with theoretical analysis and engineering examples, it constructs the duration-cost mathematical optimization model, and obtains the optimized construction schedule under the genetic algorithm solution to get the optimal construction schedule. Integrate the big data technology and computer technology more fully, improve the calculation efficiency, realize the system intelligent management optimization, provide intelligent analysis for the engineering progress management, scientifically prejudge the engineering progress information of the project, prepare the implementable construction progress plan, carry out comprehensive optimization of the construction progress, validate the feasibility and validity, and provide ideas and methods for the management of the engineering progress.

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