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SCHEDULING OPTIMIZATION IN CONSTRUCTION PROJECT BASED ON ANT COLONY GENETIC ALGORITHM

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ABSTRACT

This paper introduces the basic theory and procedure for working out solutions of ant colony genetic algorithm, describes optimization, constraints and objectives of construction project scheduling, then establishes basic model for scheduling optimization of construction project, and put forward improved ant colony genetic algorithm for solving the basic model. Performance of ant colony genetic algorithm is analyzed and evaluated from aspect of schedule - cost equilibrium in practical engineering optimization. Finally, case studies are done.

Keywords: *Ant Colony Genetic Algorithm, Construction Project, Time-Cost Optimization, Optimization Model; Case Analysis*

1. INTRODUCTION

ACA is featured in high-efficient exact solution, positive feedback and parallelism, but relatively poor global search ability; it is easy to fall into local optimum. While GA has the advantages of rapidity, randomness and global convergence, but it is sensitive to parameters, so its rate of convergence is unstable or even stagnated sometimes. The overall situation of ACA and GA can be expressed as the velocity - time curve shown in Figure 1 which indicates that in the initial search stage ($t_0 \sim t_a$),the convergence speed to optimal solution of GA is higher, but after t_a , its efficiency to seek optimal solution decreases significantly. Since ACA has no pheromone, at the beginning of the search ($t_0 \sim t_a$), the speed to search for the optimal solution is very slow, but when the pheromone is accumulated to a certain intensity (after t_a), the speed of convergence to the optimal solution rapidly increases. In order to get rid of disadvantages of ACA and GA, the two can be organically combined, to give full play to their respective advantages. The basic principle of ACA and GA fusion is that before reaching the best point (a), GA helps to generate the initial pheromone distribution, and after that, ACA is used to obtain the optimal solution[1].

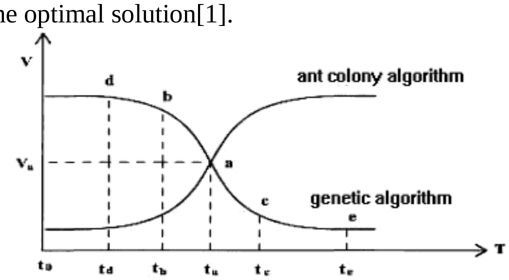

Figure 1: Velocity - Time Curve Of Ant Colony Algorithm And Genetic Algorithm [2]

Genetic and Ant Colony the Algorithm (GAAA) is the result of fused GA and ACA, aiming at giving full play to their advantages and abandoning their shortcomings, to integrate their merits as far as possible [2]. Fusion algorithm is a new heuristic method in time efficiency and solving efficiency. Accuracy of exact solutions of fusion algorithm is better than that of GA, and its time efficiency is higher than that of ACA. The overall framework of fusion algorithm is as shown in Figure 2. According to the basic design, the high speed, randomness and global convergence of GA are made full use of, so as to achieve initial information distribution of related issues. In the latter stage, ACA algorithm is adopted, with certain initial pheromone, so as to take advantage of high

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efficiency, positive feedback and parallelism of ACA to obtain exact solutions[3].

2. THE OVERALL FRAMEWORK OF ANT COLONY FUSION GENETIC ALGORITHM

The overall framework of ant colony fusion genetic algorithm is as shown in Figure 2

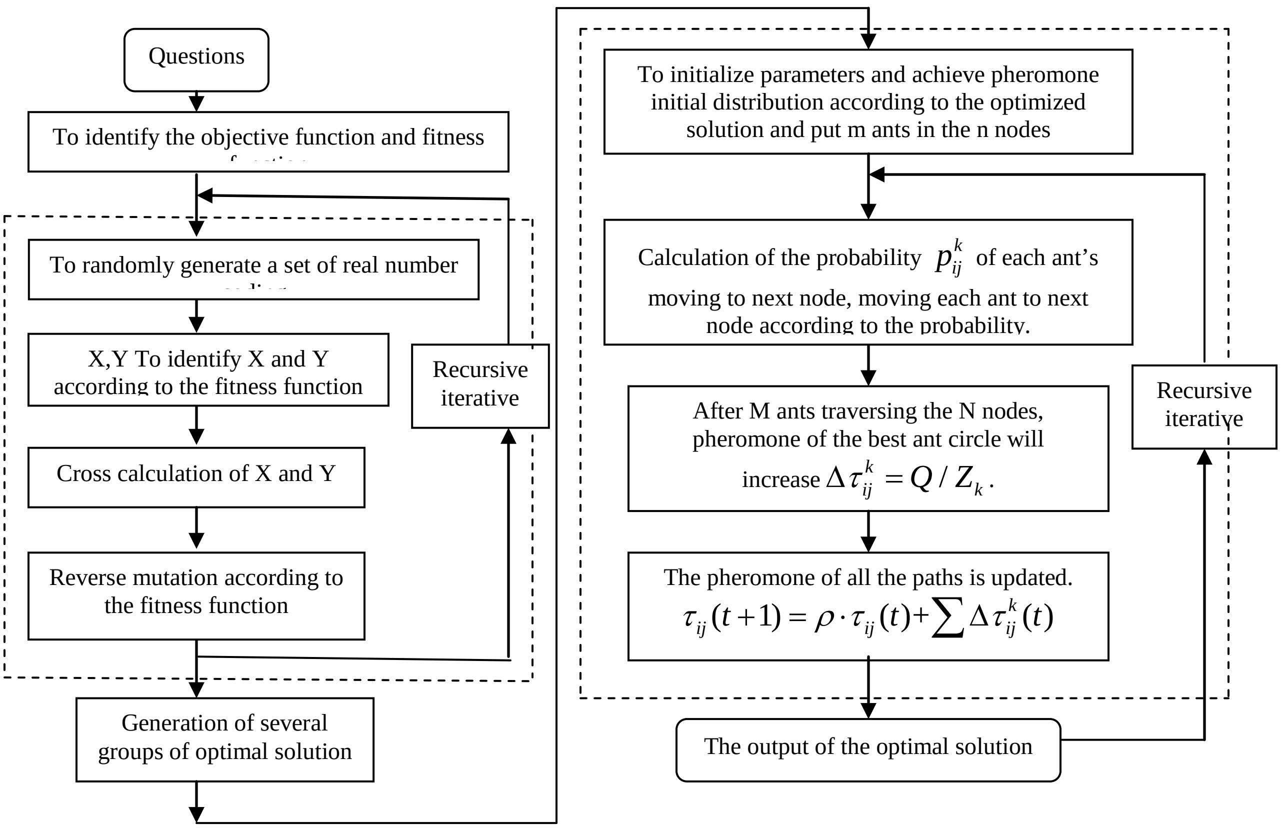

Figure 2: Framework Of Ant Colony Fusion Genetic Algorithm

a. Randomly select a mating area from the parent string, such as the two parent strings can be identified as *fuch*1 and *fuch*2 whose specific definitions are as follows:

*fuch*1= 1 2 | 3 4 5 6 | 7 8 9

*fuch*2= 9 8 | 7 6 5 4 | 3 2 1

b. If the mating area of *fuch*1 is placed before *fuch*2 whose mating area is then added before *fuch*1, then:

*fuch*1= 7 6 5 4 | 1 2 3 4 5 6 7 8 9

*fuch*2= 3 4 5 6 | 9 8 7 6 5 4 | 3 2 1

c. According to the order, the value of different mating areas are deleted in turn, the final two strings are as follows:

*zich*1= 7 6 5 4 1 2 3 8 9

*zich*2= 3 4 5 6 9 8 7 2 1

3. DESCRIPTION OF OPTIMIZATION OF THE PROJECT SCHEDULE

Optimization of the project schedule mainly refers to optimization of time and cost in the implementation stage of project construction[4], including that of time and schedule – cost and the main involved constraint conditions to be satisfied contains:

a. The time period from node i to j must be between the shortest time and normal time;

b. When the time of critical procedure is shortened, critical path shall not be changed;

c. The direct cost of each procedure should be controlled between that required for normal time duration and that for the shortest time duration, and the direct cost after the change and the time duration of corresponding procedure should meet a two-order relationship;

d. The direct cost rate of each procedure = (direct costs for the shortest time duration - that for

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normal time duration)/ (normal time duration - the shortest time duration)[5].

4. OPTIMIZATION MODEL OF CONSTRUCTION PROJECT SCHEDULE

According to the above description about construction project, the following mathematical model of schedule-time optimization can be established [6]:

Definitions of variables:

$$x_{ij}=\begin{cases}1 & \text{i - j is the key work}\\ 0 & \text{i - j is not the key work}\end{cases} \quad (1)$$

$$y_{ij}=\begin{cases}1 & \Delta C_{ij}^{0}<\Delta C_{ij}^{k}\\ 0 & \Delta C_{ij}^{0}\ge \Delta C_{ij}^{k}\end{cases} \quad (2)$$

Mathematical model:

$$MinC=\sum_{i=1}^{n-1}\sum_{j=2}^{n}C_{ij}^{D}+\sum_{i=1}^{n-1}\sum_{j=2}^{n}C_{ij}^{D}\Delta C_{ij}^{k}+\sum_{i=1}^{n-1}\sum_{j=2}^{n}\Delta t_{ij}(\Delta C_{ij}^{0}-\Delta C_{ij}^{k})y_{ij} \quad (3)$$

$$MinFT=\sum_{i=1}^{n-1}\sum_{j=2}^{n}t_{ij}x_{ij} \quad (4)$$

$$\text{s.t} \quad t_{ij}\ge 0 \quad (5)$$

$$t_{ij}^{N}\le t_{ij}\le t_{ij}^{L} \quad (6)$$

$$\Delta t_{ij}=t_{ij}^{L}-t_{ij} \quad (7)$$

$$C_{ij}^{n}\le C_{ij}^{D}\le C_{ij}^{l} \quad (8)$$

$$C_{ij}^{D}=\alpha_{ij}t_{ij}^{2}+\beta_{ij} \quad (9)$$

$$\alpha_{ij}=[C_{ij}^{N}-C_{ij}^{L}]/[(t_{ij}^{N})^{2}-(t_{ij}^{L})^{2}] \quad (10)$$

$$\beta_{ij}=[C_{ij}^{L}(t_{ij}^{N})^{2}-C_{ij}^{N}(t_{ij}^{L})^{2}]/[(t_{ij}^{N})^{2}-(t_{ij}^{L})^{2}] \quad (11)$$

$$\Delta C_{ij}^{0}=\frac{C_{ij}^{l}-C_{ij}^{n}}{t_{ij}^{L}-t_{ij}^{N}} \quad (12)$$

Note: (1) and (2) are definitions of variable; (3) is the objective function to allow the minimum total project cost; (4) is the objective function to allow the shortest project time duration; (5) and (6) are constraints for time duration of each procedure; (7) is the constraints for shortened time duration of each key procedure; (8), (9), (10) and (11) are constraints for direct cost of procedure $i-j$; (12) is constraint for formula of indirect cost rate[7].

$$MinC=\sum_{i=1}^{n-1}\sum_{j=2}^{n}C_{ij}^{D}+\sum_{i=1}^{n-1}\sum_{j=2}^{n}C_{ij}^{D}\Delta C_{ij}^{k}+\sum_{i=1}^{n-1}\sum_{j=2}^{n}\Delta t_{ij}(\Delta C_{ij}^{0}-\Delta C_{ij}^{k})$$

is the objective function to allow the minimum total project cost; $\sum_{i=1}^{n-1}\sum_{j=2}^{n}C_{ij}^{D}$ is the total direct costs of construction project, $\sum_{i=1}^{n-1}\sum_{j=2}^{n}C_{ij}^{D}\Delta C_{ij}^{k}$ is the total indirect cost of construction project, $\sum_{i=1}^{n-1}\sum_{j=2}^{n}\Delta t_{ij}(\Delta C_{ij}^{0}-\Delta C_{ij}^{k})$ is the sum of compressed direct and indirect costs of the construction project.

$MinFT=\sum_{i=1}^{n-1}\sum_{j=2}^{n}t_{ij}x_{ij}$ is the target function to allow the shortest time duration of construction project; $\sum_{i=1}^{n-1}\sum_{j=2}^{n}t_{ij}x_{ij}$ is total time limit for critical path.

5. SOLVING STEPS OF OPTIMIZATION ALGORITHM FOR CONSTRUCTION PROJECT SCHEDULE

Solution to ant colony fusion genetic algorithm and its corresponding schedule-time contains the following steps:

(1) Initialize α, β, m, ρ and other parameters, and divide the solution space into several sub space according to the dimension for optimization (such as the shortest time duration and the lowest cost) and constraints for time duration of each procedure and constraints for direct cost of each procedure. Calculate the total cost of the project;

(2) Put m ants on the initial point which is then applied into the current solution set $tabu_k(s)$;

(3) Transfer each ant k (k=1, 2, 3, ... m) to the next node j according to the state transition probability formula and apply node j into $tabu_k(s)$;

(4) Calculate the time duration Tm of the mth ant, update the route of the longest time duration;

(5) Update pheromone of each procedure (i, j), according to the formula (12);

(6) Calculate $\tau_{ij}(t+n)=\rho\tau_{ij}t+\Delta\tau_{ij}$ of each procedure (i, j), apply t← t+n, NC← nc+1 on each edge, set $\tau_{ij}\leftarrow 0$;

(7) Check whether the constraints are satisfied, if they are satisfied, identify FT total time duration of critical path, otherwise, turn to step (2);

(8) Update the amount of information in the subspace, the parent will be got by information, objective function and other comprehensive factors;

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(9) Select some excellent decisions from decision set and add them to parent, after crossover and mutation, eliminate infeasible decisions;

(10) Have recursive hierarchy for optimal and updated decision;

(11) Check whether the constraints are satisfied, if they are satisfied, identify the optimal decision and algorithm convergence condition, otherwise, turn to step (8).

6. PERFORMANCE ANALYSIS OF OPTIMIZATION ALGORITHM OF CONSTRUCTION PROJECT SCHEDULE

Take schedule-time equilibrium of schedule optimization of construction project as an example, we will verify the superior performance of improved ant colony genetic algorithm.

We can see from Table 1, the results of the two variable constraints from colony fusion genetic algorithm are better than multi-objective genetic algorithm, and the solutions are more widely spread.

Table 1: Comparison Of The Two Algorithms In Standard Deviation (Or Distance) And Maximum Scatter Extent

Algorithm	Number of solutions	Standard deviation (S)	Maximum scatter extent
Multi-objective genetic algorithm	125	0.0030	4.03
Improved algorithm	114	0.0024	5.26

The analysis shows that the result of multi-objective genetic algorithm is between 0~ 0.9 and that obtained from the improved ant colony genetic algorithm is between 0~1, which means the distribution of the latter is better[8].The analysis shows the iteration global convergence from the improved ant colony genetic algorithm is quick, a total of 77 times, and 162 times in multi-objective genetic algorithm.

7. CASE STUDIES ABOUT PROJECT SCHEDULE OPTIMIZATION

A construction project covers 51067 m^2, with total construction area of 240000 m^2. This project consists of commercial buildings 1# and 2#, residential buildings 3# - 12#, one-layer underground garage. Residential building consists of 10-30 layers of floors whose floor height is 2.9m. The planned time duration for this project is 145 weeks, and the planned investment is 32 million yuan.

7.1 Schedule Optimization of Ant Colony Fusion Genetic Algorithm of Construction Project

Schedule-time optimization of construction project with improved ant colony fusion genetic algorithm can be divided into the following steps:

7.1.1 parameter settings

Firstly, set the necessary parameters of ant colony fusion genetic algorithm; the maximum number of iterations of the ant colony operation nc-max=200, heuristic information factor α =1, ant number m=11, expected heuristic factor β =4, pheromone evaporation coefficient =0.5, the constant q0=0.8, t= 0, mutation probability PM=0.1, crossover probability PC=0.7, and ΔC_{ij}^{k} =0.2 million / week.

Specific parameter settings are as shown in Table 2:

Table 2: Parameter Setting

α	β	ρ	m	q_0	nc-max	PM	PC	t
1	4	0.5	11	0.8	200	0.1	0.7	0

7.1.2 examples of basic data

The basic data contains three parts: No. of each procedure in the project, time duration and direct cost . The pair of No. and name of corresponding procedure is as follows(normal time duration and the shortest; normal time duration and the shortest): A-foundation excavation and slope support(11,10;0.8,1.2), B-pile foundations (16,14;3.6,3.2), C-thermal layer and waterproof layer(8,7;0.8,1), D- basement structure (13,11;1.4,1.5), E-electrical pipelines, water supply and drainage, embedded-reserved heating ventilation (75,70;0.5,0.6), F- exterior wall waterproof and outdoor backfill of basement (14,13;1.1,1.4), G -the main structure (27,25;4.8,5.4), H - frame erection (42,,40;0.5,0.9), I - basement masonry and backfill (14,12;1,1.2), J - the main masonry and plastering(38,35;2,2.4), K - tower structure(9,8;1.6,1.8), L - the removal of frame (46,43;0.5,0.7), M - roof project (9,8;2,2.5), N exterior wall decoration and interior decoration (17,15;2,2.5), O – installation of windows and doors (13,12;1,1.3), P–water and electricity supply, elevator installation and debugging (12,10;2,2.3), Q-outdoor project (10,8;1,1.2), R - completion and acceptance (5,4;0.6,0.8).Before optimization, the direct cost of all procedures for normal time duration is 26.8 million yuan, and that of the shortest time duration is 32.3 million yuan.

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7.1.3 schedule-time optimization

Schedule-time optimization is based on ant colony fusion genetic algorithm. The main process is to find critical path and non critical path by using ant colony algorithm, and work out optional solution with genetic algorithm. The optimization principle is that the direct cost rate is less than the rate of indirect cost and the total cost should be decreased; compress the procedures in sequence from the lowest rate of direct costs to the highest. Repeat the process until the time when further compressed time duration of any procedure will make the total project cost increase.

7.1.4 results

Apply the basic data and information related to the project from the interface into the simulated algorithm software, click the "calculate" button, then we can work out the solutions with the help of ant colony fusion genetic algorithm based on the data provided. The optional solutions to Hope City project with improved ant colony genetic algorithm show that the total time duration is 144 weeks, shorter than 145 weeks which is defined by project planning. With the optimization solution, total cost of the project is reduced to 30.89 million yuan from 33.96 million yuan which is the result before optimization, which means obvious optimization effect is achieved.

7.2 Results of construction project schedule optimization

The planned period for this project is 145 weeks, and the planned investment is 32 million yuan. Before optimization, the planned period is 151 weeks and the planned total cost of the project is 33.96 million yuan, however, with the help of improved ant colony genetic algorithm for solving the optimal randomized solutions for 97 times, the optional time duration and optimal total cost of each procedure of the project are achieved as is shown in Figure 3. After optimization, the optimal time duration optimal total cost are respectively: t={11, 16, 8, 11, 71, 14, 27, 42, 13, 36, 9, 43, 9, 17, 13, 11.5, 8, 5}, C={0.96, 3.84, 0.96, 1.38, 1.4, 1.32, 5.76, 0.6, 0.8, 2, 1.92, 0.2, 2.4, 2.4, 1.2, 2.03, 1, 0.72}; optimized total time duration is 144 weeks, shorter than planned period of 145 weeks; the total cost is 30.89 million yuan, namely 1.11 million yuan less than planned total investment; compared with the results before optimization, the total construction period is shortened by 7 weeks, the total cost reduction is reduced by 3.07 million yuan. Therefore, ant colony fusion genetic algorithm to work out solutions for construction project schedule-time optimization can achieve good results.

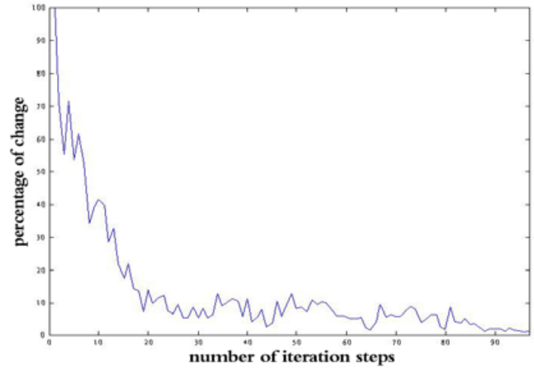

Figure 3: Percentage curve of iterative change of the optimization procedures

8. PERFORMANCE ANALYSIS OF OPTIMIZATION ALGORITHM OF CONSTRUCTION PROJECT SCHEDULE

The improved automatic ant colony genetic algorithm can help to solve the problems about schedule-time equilibrium. The results show that, the improved ant colony genetic algorithm is suitable for solving the construction project schedule-time optimization, and its performance in optimization is better to some degree. The optimized precision can meet developers' demand; therefore the improved ant colony genetic algorithm can quickly and effectively help the project manager with schedule - cost optimization, providing better services for the real estate developers.

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