Scheduling Optimization of Construction Engineering based on Ant Colony Optimized Hybrid Genetic Algorithm

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Abstract—**In this paper, the basic theory and procedure for working out solutions of ant colony genetic algorithm were first introduced; the optimization, constraints and objectives of construction project scheduling were described; then a basic model for optimization of construction project scheduling was established; and an improved ant colony genetic algorithm for solving the basic model was put forward. Performance of ant colony genetic algorithm was analyzed and evaluated from the aspect of schedule - cost equilibrium in practical engineering optimization. Finally, case studies were provided.**

With the rapid development of the present society, urban development increases the demand for construction projects in the process of urban construction, but the existing construction project scheduling is unable to meet the increasing needs of construction efficiency of urban development. So in this paper, a project scheduling optimization method with synergy of ant colony optimization genetic algorithm was proposed. The optimization method successfully integrated ant colony algorithm and genetic algorithm into construction project scheduling, and improved the construction project scheduling through reasonable optimization algorithm. Case analysis shows that the construction project scheduling optimization method based on ant colony optimization genetic algorithm greatly optimized the actual project cost of capital and greatly improved the scheduling efficiency.

Index Terms—**Ant colony genetic algorithm, Construction Project, Time-cost optimization, Optimization model; Case analysis**

I. Introduction

Ant colony algorithm (ACA) is featured by high-efficiency exact solution, positive feedback and parallelism, but relatively poor global search ability and high likelihood to falling into local optimum. On the contrary, genetic algorithm (GA) has the advantages of rapidity, randomness and global convergence. However, GA is sensitive to parameters, so its rate of convergence is unstable or even stagnated sometimes. The overall situations of ACA and GA can be expressed as the velocity - time curves in Fig. 1. In the initial search stage ($t_0 \sim t_a$), GA has a higher convergence speed to optimal solution, but after t_a, its efficiency to seek optimal solution is decreased significantly. Since ACA has no pheromone, its speed to search for the optimal solution is very slow during $t_0 \sim t_a$, but when the pheromone is accumulated to a certain intensity after t_a, its speed of convergence to the optimal solution is rapidly increased. In order to abandon the disadvantages of ACA and GA, the two algorithms can be organically combined to make full use of 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 [1-3].

Ant Colony Genetic Algorithm results from the fusion of Genetic Algorithm(GA) and Ant Colony Algorithm (ACA), aiming utmost integrating their merits by making full use of their advantages and abandoning their shortcomings [4-5]. Ant Colony Genetic Algorithm is a new heuristic method in improving time efficiency and solution efficiency. Ant colony genetic algorithm has a higher accuracy of exact solution than GA, and a higher time efficiency than ACA. The overall framework of ant colony genetic algorithm is shown in Fig. 2. According to the basic design, the high speed, randomness and global convergence of GA are fully used to achieve initial information distribution of related issues. In the latter stage, the high efficiency, positive feedback and parallelism of ACA with certain initial pheromone are taken advantage of to obtain exact solutions [6-8].

doi:10.4304/jnw.8.6.1411-1416

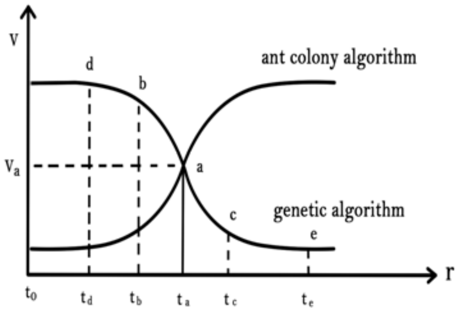

Fig. 1. Velocity - time curves of ant colony algorithm and genetic algorithm

Based on the shortcomings of slow search speed, easily falling into local optimal of ant colony algorithm, the paper combines it with genetic algorithm to solve specific problems, and which is a good way. No matter in what kind of typical hybrid method, however, it is to set up a fixed number of iterations to control invoking of two kinds of algorithms, and this is likely to cause the phenomena that precocious or degraded populations is still in the useless iteration, making a slow convergence speed. Combining with the advantages of ant colony algorithm and genetic algorithm, this paper proposes a new ant colony genetic hybrid algorithm. The new algorithm adopts the best combination point evaluation strategy to dynamically cross invoke two kinds of algorithms, and designs the corresponding pheromone updating method according to the framework, improving the convergence rate of the algorithm; simultaneously introduces iterative adjusting threshold to control the genetic operation and ants scale in the upper stage of the algorithm, so as to find the optimal solution more quickly [9-11].

According to construction project scheduling problem, the paper mixes the ant colony algorithm and genetic algorithm for fusion and dynamic cross use, which improves the convergence speed of the algorithm and improves the transfer efficiency of construction project [12, 13].

Ⅱ.OPTIMIZATION MODEL

According to the above description about construction project, the following mathematical model of schedule-time optimization can be established [14]:

Definitions of variables:

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

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

Mathematical model:

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

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

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

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

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

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

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

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

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

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

Note: Eq. (1) and Eq. (2) are definitions of variables; Eq. (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 constraint 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[15-18]. That mean:

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

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 subspaces according to the dimension for optimization (e.g. the shortest time duration or the lowest cost) and the constraints for time duration of each procedure and constraints for direct cost of each procedure. Calculate the total cost of the project[19-20];

(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 T_m of the $m-th$ ant, and update the route of the longest time duration;

(5) Update pheromone of each procedure (i, j) according to Eq. (12);

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

(7) Check whether the constraints are satisfied; if yes, identify FT total time duration of the 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;

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

(10) Create a recursive hierarchy for the optimal and updated decision[21-23];

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

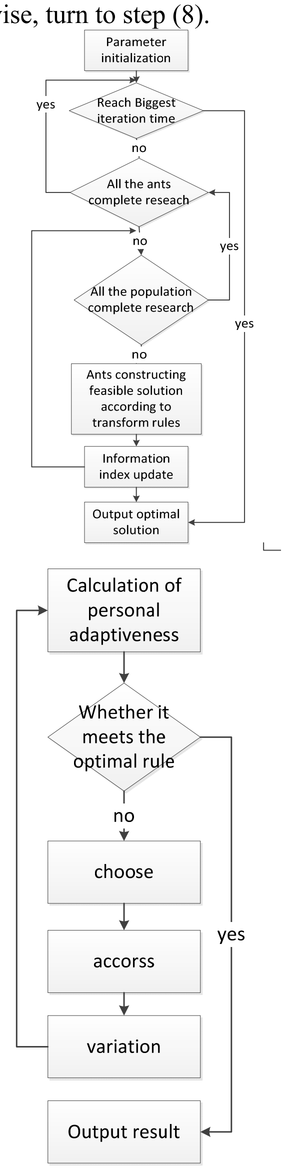

Fig. 4. Flow chart of Ant colony optimization hybrid genetic algorithm

III. Experimental Results

Scheduling problem gets researchers' extensive research due to its strong engineering application background. However, scheduling problem is a typical NP Hard problem, its characters of complexity, multi-objective, randomness; binding, etc. brought great difficulties to research.

Based on a heavy calculation of this kind of construction project, the data access thus uses a batch of computer system which can provide model storage and indicate the model as experimental environment, it is used to store model code, because we use model indicate method based on facing object method, so the model storage stores the model object set in logical, such models can be serve as a sample of the experiment.

The schedule-time equilibrium of schedule optimization of construction project was taken as an example to verify the superior performance of the improved ant colony genetic algorithm.

Table 1 shows that, the results of the two variable constraints from colony fusion genetic algorithm are better than those of the multi-objective genetic algorithm, and the solutions are more widespread.

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

Experimental results show that there are 125 feasible solutions of multi-objective genetic algorithm, and the number of solution of optimal improved ant genetic algorithm is 114, by contrast, the latter has less choice, which is more oriented to be optimized, the standard deviation result of multi-objective genetic algorithm is 0.03, and which of the improved ant colony genetic algorithm is 0.0024, the deviation of improved ant colony genetic algorithm is smaller, and which is also oriented to be optimized. By contrast, the greatest divergence of Multi-objective genetic algorithm is 4.03, which is smaller of 1.23 than the improved divergence, so the analysis results show that: the global convergent iterative improved ant colony genetic algorithm (total 77 times) is superior to multi-objective genetic algorithm (162 times) in the calculation speed, which is by comparison, the improved ant colony genetic algorithm has a higher running efficiency, and more optimized.

The studied construction project covers 51067 m^2, with a total construction area of 240000 m^2. This project consists of commercial buildings 1# and 2#, residential buildings 3# - 12#, and a one-layer underground garage. Each residential building consists of 10-30 floors (each 2.9 m high). The planned time duration for this project is 145 weeks, and the planned investment is 32 million yuan.

A. Schedule Optimization

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

Firstly, set the necessary parameters for the ant colony fusion genetic algorithm; the maximum number of iterations of ant colony operation nc-max=200, heuristic information factor α =1, number of ants m=11, the expected heuristic factor β =4, pheromone evaporation coefficient ρ=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 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

The basic data contain 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 time duration; normal time duration and the shortest time duration):

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 -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 - main masonry and plastering(38, 35; 2, 2.4),

K - tower structure(9, 8; 1.6, 1.8),

L - 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),

and 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 for the shortest time duration is 32.3 million yuan.

Schedule-time optimization is based on ant colony fusion genetic algorithm. The main process is to find the critical path and non-critical path by using ant colony algorithm, and work out optional solution by using genetic algorithm. The optimization principle is that the direct cost rate is less than the indirect cost rate and the total cost should be decreased; the procedures in sequence will be compressed by direct cost rate from the lowest to the highest. The process will be repeated until the further compressed time duration of any procedure will increase the total project cost. Using iterative adjustment threshold t to adjust the genetic algorithm and the ant population size of upper hybrid algorithm: (1) as for genetic algorithm, in addition of guaranteeing the excellent genetic pattern of the population will heredity to the next generation, it further expands the search space through mutation, which is advantageous to the next ant colony algorithm to search a better solution. (2) as for the ant colony algorithm, it properly increase the population scale upper the algorithm, which is conducive to better play its local optimization ability, and find the optimal solution more quickly.

TABLE3
COMPARISON OF EXPERIMENTAL RESULTS BETWEEN DIFFERENT ALGORITHMS

Experiment data	Optimal solution	Average time (10)	Iteration time
Genetic algorithm	447.986	488.235	5000
Ant colony algorithm	428.5862	432.652	1000
Hybrid genetic algorithm	421.5263	425.1258	500

We apply the basic data and information related to the project from the interface into the simulated algorithm software, and by clicking the button "calculate", 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 from the improved ant colony genetic algorithm show that the total time duration is 144 weeks, shorter than one defined by the project planning, which is 145 weeks. 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, indicating an obvious optimization effect.

B. Results

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 is 33.96 million yuan. However, with the help of the improved ant colony genetic algorithm for solving the optimal randomized solutions for 97 times, the time duration and the total cost of each procedure of the project are optimized (Fig. 3). After optimization, the optimal time duration and the 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}. The optimized total time duration is 144 weeks, shorter than the planned period of 145 weeks. The optimal total cost is 30.89 million yuan, which is 1.11 million yuan less than the planned total investment. Compared with the results before optimization, the total construction period is shortened by 7 weeks, and the total cost is reduced by 3.07 million yuan. Therefore, ant colony fusion genetic algorithm can work out good solutions for construction project schedule-time optimization.

We can conclude according to the results that in relative to element algorithm, the expected total lasting time of the adjustment of hybrid ant colony genetic algorithm scheduling construction projects is less of one week compare to the planning time of the project, which greatly improves the work efficiency of project adjustment, and saves the cost, according to the conclusions above, we can obtain that the total cost is lower of 3.07 million yuan compare to the original suboptimal project cost by the hybrid ant colony genetic algorithm proposed in this paper, and the optimal result of this adjustment is relatively satisfactory. Compared to the results, the final optimal degree of this algorithm is 97 times of original algorithm computing degree, the optimal lasting time of the algorithm and total cost of each procedure is superior to the original algorithm which can be concluded:

New algorithm uses the optimal fusion point evaluation strategy to dynamically control the opportunity of two algorithms of cross and invoking. We can guarantee a certain times of evaluation of the population by setting the minimum operation and maximum iteration times, within the scope of the set iterations number, we determine whether to invoke the ant colony algorithm through the evaluation strategy. Which means it gives full play to both the global search ability of genetic algorithm and local optimization ability of ant colony algorithm, effectively avoid the problem of premature call (not convergence to local optimal) or late call (population have been precocious), and also greatly reduce the overall optimization iterations, making the population converge to the optimal solution as soon as possible, improving convergence rate of the algorithm, improved the update methods of pheromone. These three times of update operations can effectively improve the accumulation speed of pheromone, and can quickly reflect the superiority of various paths and the heuristic information of algorithm, which not only improves the searching efficiency of spatial search, but also shorten the search speed of the algorithm. We design the iterative adjustment threshold to adjust the genetic operation upper the algorithm and the scale of ant colony. This method can not only avoid the destroy of excellent genetic model in genetic populations and reduce the workload of genetic calculation, but also make the algorithm find out the optimal solution more quickly by properly increasing the ant scale.

In traditional algorithms, because only the ant swarm algorithm solution and the global optimal solution is used to update the pheromone, so leading to a low speed of the accumulation of the pheromone, which cannot reflect the algorithm of heuristic information. as soon as possible. So based on this, the new algorithm of the article finds out the optimal individual from each generation of the population, and updates the pheromone by taking this as the pheromone. At the same time, because the new algorithm uses the best combination pointed assessment strategy to ensure the evaluation direction of the population, so compared with the pheromone update methods in traditional ant colony genetic hybrid algorithm, the proposed hybrid ant colony genetic algorithm can reflect the merits and demerits of the various paths more quickly, and it guides the population evaluation thought according to the positive feedback learning process represented by the pheromone in ant colony algorithm, the hybrid ant colony genetic algorithm is better able to guide the next ant optimization operation, so as to find the optimal solution as soon as possible.

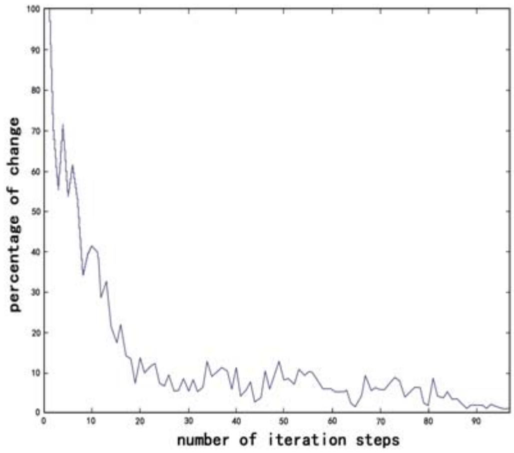

Fig. 4 Percentage curve of iterative change of the optimization procedures

TABLE IV. COMPARISON OF PROJECT TOTAL COST AND ORIGINAL PROJECT PLAN AFTER APPLICATION OF ANT COLONY FUSED GENETIC ALGORITHM

Plan cycle of original project	Total cost of original project	Plan cycle of original algorithm mixed with genetic algorithm	Total cost of original algorithm mixed with genetic algorithm
11	0.96	11	0.82
16	3.84	16	3.56
8	0.96	7	0.72
11	1.38	11	1.25
71	1.4	71	1.3
14	1.32	14	1.25
27	5.76	27	4.28
42	0.6	42	0.56
13	0.8	13	0.66
36	1.92	36	1.58
9	0.2	9	0.18
43	2.4	42	2.35
9	2.4	9	2.35
17	1.2	17	1.15
13	2	13	2
11.5	1.5	11.5	1.5
8	1.2	8	1.2
5	1.5	5	1.5

IV. CONCLUSION

The improved automatic ant colony genetic algorithm can help to solve the problem of schedule-time equilibrium. The results show that, the improved ant colony genetic algorithm is suitable for solving the schedule-time optimization for construction projects, and its performance in optimization is somewhat higher. The optimized precision can meet developers' demand, so the improved ant colony genetic algorithm can quickly and effectively help the project manager with schedule - cost optimization, and provide better services for the real estate developers.

ACKNOWLEDGMENT

This work was Supported by the special Fund for Basic Scientific Research of Central Colleges, Chang'an

University and the Support Plan Special Fund of Chang'an University Basic Research CHD2011JC116(2011209); Ministry of housing and Urban-Rural Construction Soft Science Fund(2011-R1-26;2011-R3-19); Shaanxi Soft Science Fund (20llKRM20); Shaanxi Social Sciences 2012 major theoretical and practical issues research project (2012C008); Highway Maintenance under Low Carbon Economy(2171-20130186); Shaanxi Social Science Fund(llE177); Xi'an Soft Science Fund HJ1112 (1). The authors wish to thank professor Yi-fan Tang's kindness and help, and assistant professor Hai-yan xie (university of Arkansas Little Rock, USA)'s constructive suggestion.

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