Genetic Algorithms for Optimization of Resource Allocation in Large Scale Construction Project Management

Jian-wen Huang*
College of Hydraulic & Environmental Engineering, China Three Gorges University, Yichang, China
Email: javenhuang@126.com

Xing-xia Wang and Rui Chen
College of Hydraulic & Environmental Engineering, China Three Gorges University, Yichang, China
Email: wangxingxia1980@126.com

***Abstract*—It is well known that a construction project is the process of resource consumption. Especially for large project, more kinds of resources are involved and the amount is very huge. In construction process of a project, the resource is limited and the time is very urgent, so for large scale project management there are some important subjects such as how to effectively distribute resources between each activities and how to effectively utilize limited resources. Therefore, it's of great importance to optimize the allocation of construction resource. This paper analyzes existing problems of resource allocation for large scale project, such as shortest construction duration with limited resource and resource leveling with stationary construction duration. Based on that, the corresponding mathematical optimization model is established and solution method on the basis of genetic algorithm is given. Comparing with traditional methods, better results are given when genetic algorithm is used, which can not only compress project duration in maximum, but also reasonably arrange activity starting time in uncritical path, and adjust the order of resource in different activities, to lower the peak of dynamic resource distribution curve as much as possible and to make resource consumption be in equilibrium state. Application in an engineering case shows that genetic algorithm can solve relative problems of resource allocation optimization in network planning for large-scale project very well and will be widely used in project optimization.**

***Index Terms*—resource allocation, resource leveling, Genetic Algorithms, optimization, large-scale construction project**

I. INTRODUCTION

It is well known that a construction project is the process of resource consumption. Especially for large projects, the type of consumption of resources is various and the quantities are large. For a large project, the resources may be labour, asset, material(such as earth-rock excavation, normal concrete pouring, roller-compacted concrete pouring and so on), or capital which can be used to accomplish a goal. Resource allocation problem is the process of allocating resources among the various projects or activities of a project for maximization of profit, minimization of cost or shortest duration. The process of the resource allocation seeks to find an optimal allocation of a limited amount of resource to a number of tasks for optimizing their objectives subject to the given resource constraint. During the construction process, the project cannot be sustained to meet the various requests for resources due to the interference of various uncertain factors. It will inevitably bring about implementation constraints which will hinder the achievement of project objectives and maximize the benefits. Therefore, it is significant to rationally optimize and allocate the resources in the construction process[1].

Resource allocation, sometimes referred to as constrained-resource scheduling, attempts to reschedule project tasks so that a limited number of resources can be efficiently utilized while keeping the unavoidable extension of the project to a minimum. Because of their practical applications, resource allocation problems have been studied intensively in the field of construction. Early techniques to solve those problems used mathematical models, such as integer programming, branch-and-bound, linear programming, or dynamic programming [2]. At present, mathematical programming method only can solve one aspect of this problem but it cannot get the optimal solution. However, when the problem is too large, some deterministic algorithm such as linear programming method, branch-and-bound method cannot give the optimal solution at acceptable time. Genetic Algorithm is an effective evolutionary algorithm. Many investigators have reported that Genetic Algorithm has a strong ability to find the Global Optimum Results[3].

In this paper, a new approach, employing the use of Genetic Algorithms, is developed to search for the optimum solutions of shortest construction duration with

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*Corresponding author.

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limited resource and resource leveling with stationary construction duration. Based on that, the corresponding mathematical optimization model is established and solution method on the basis of Genetic Algorithm is given. At the same time it is applied in an engineering project, The result shows that Genetic Algorithm can solve relative problems of resource allocation optimization in network planning for large-scale project very well and will be widely used in project optimization.

II. Establishment of the Optimization Model

A. The Optimization Model of the Shortest Duration with Limited Resources

A project such as a construction project consists of a network of activities and a node in network corresponds to an activity. Each activity in a project has a corresponding duration and also needs certain amount of resources such as labor or material to execute itself with them[4]. The aim of "limited resources, the shortest duration" is to make the daily resource requirement no more than the daily supply, to make full use of limited resources and make the total duration as short as possible. In the optimization of the shortest duration with limited resources, the optimization should not only adjust the non-critical activities, but also adjust the critical activities sometimes. So the objective of resource allocation problem is to find the shortest project duration by allocating the available resources which are constrained to some maximum value to project activities.

The mathematical description of resource allocation optimization is expressed as follows:

$$T = \min\{\max\{t_i + d_i \mid i = 1, 2, \cdots, n\}\} \quad (1)$$

s.t.

$$t_j \geq t_i + d_i ; \forall j \in S_i \quad (2)$$

$$\sum_{t_i \in A_{t_i}} r_{t_i k} \leq b_k \qquad (k = 1, 2, \cdots, m) \quad (3)$$

$$M_i \leq d_i \leq N_i \qquad (d_i, t_i \geq 0; i = 1, 2, \ldots, n) \quad 4)$$

$$LES_i \leq AS_i \leq LLS_i \quad (5)$$

$$LEF_i \leq AF_i \leq LLF_i \qquad (i = 1, 2, \ldots, n) \quad (6)$$

where T = project duration; t_i = starting time of activity i; d_i = duration of activity i; A_{t_i} = set of ongoing activities at date t_i; $r_{t_i k}$ = the k^{th} resource requirement of activity i at date t_i; b_k = resource limit of the k^{th} resource; M_i = crash duration of activity i; N_i = normal duration of activity i; LES_i = limited earliest start time of activity i; AS_i = actual start time of activity i; LLS_i = limited latest start time of activity i; LEF_i = limited earliest finish time of activity i; AF_i = actual finish time of activity i; LLF_i = limited latest finish time of activity i.

B. The Optimization Model of the Resource Leveling with Stationary Duration

When the duration of a project is stationary, it is necessary to consider the rational utilization of each resource requiring in the project. If the plan is failure, there must be the "peak" or "valley" of resource requirement on the same time. It is the phenomena of resource waste [5]. So optimization of the resource leveling with stationary duration is to level the resource consumption by adjusting the start time and completion time of each activity on non-critical path. The objective function of resource leveling optimization can be defined as various forms. In this paper, the objective function is weighted standard deviation of the resource requirements which is called weighted resource leveling coefficient, and the smaller the standard deviation is, the better the resource leveling degree is. So the weighted resource leveling coefficient can be calculated by following formula:

$$D = \min\{\sum_{k=1}^{m} w_k \sigma_k\} \quad (7)$$

s.t.

$$TS_i - ES_i \leq TF_i \qquad TS_i \geq 0, \quad i = 1, 2, \cdots, n \quad (8)$$

In formula (7) and (8), w_k means the weight of the k^{th} resource, generally it can calculated according to cost proportion of the k^{th} resource; σ_k is the resource consumption standard deviation of the k^{th} resource which can be calculated by the following formula (9); TS_i means actual start time of activity i; ES_i means earliest start time of activity i; and TF_i means total float time of activity i.

$$\sigma_k = \sqrt{\frac{1}{T}\sum_{q=1}^{T}\sum_{i=1}^{n}\left(r_{kiq} - \overline{r_k}\right)^2} \quad (9)$$

In formula (9), T is the duration of the project; r_{kiq} is the k^{th} resource requirement of activity i on q^{th} day; and $\overline{r_k}$ is the daily average requirement of the k^{th} resource which can be calculated by following formula:

$$\overline{r_k} = \frac{1}{T}\sum_{i=1}^{n} r_{ki} d_i \quad (10)$$

where r_{ki} is the k^{th} the daily resource requirement of activity i.

III. Models solution based on Genetic Algorithm

A. Basic Theories

In the recent years, Genetic Algorithm has been the subjects of interest. The striking feature of this algorithm is that it is based on ideas from the science of biological genetics and the process of natural selection[6]. It is introduced in the United States in the early 1970's by J.Holland and it is an outstanding method to solve the complex optimization problem. It has been widely used in many fields, such as function optimization, combination optimization, neural network optimization, programming optimization and so on.

From the mathematical point of view, GA is essentially a search optimization technique that collectively known as “evolutionary computing”. The major benefits of this algorithm is that they provide a robust search in complex spaces and are usually less expensive, as far as computation is concerned, when compared to most other optimization solutions[7]. Some of the characteristics of GA compared to normal optimization search procedures are: (1) Smart search; (2) Progressive optimization; (3) Global optimal solution. (4) Black-box structure; (5) Good versatility; (6) Parallel-type algorithm; (7) Intrinsic learning; (8) Stability.

Most of the genetic algorithms have three main operators [8]: 1)Selection; 2)Crossover and 3)Mutation.

The Genetic Algorithm is performed in the following steps:

Step 1: Population initialization;

Step 2: Calculate the fitness value of each individual;

Step 3: Selection;

Step 4: Crossover;

Step 5: Mutation;

Step 6: Analyze the stop condition, if meet stop condition, go to step 7, else go to step 2;

Step 7: Output the individual with best fitness value.

The process of the Genetic Algorithm can be described as Fig.1.

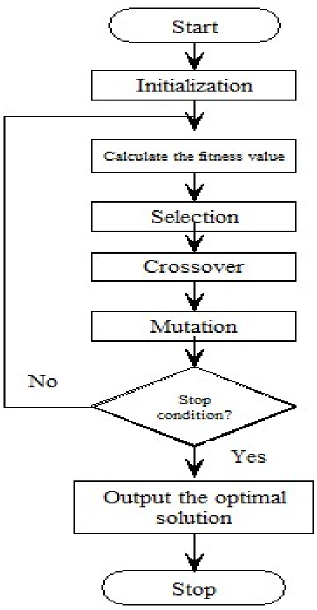

Figure 1. Flowchart of the Genetic Algorithm

B. Genetic Algorithm Design

- The Optimization Model of the Shortest Duration with Limited Resources

(1)Chromosome Structure

The shortest duration problem with limited resources could be considered as a class of scheduling problems subject to certain constraints, because once the order is given, the earliest start time of each activity is very easy to determine according to the available resources[9]. Here a list of activities in good order is adopted to code the chromosome of the issue, the actual start time of each process is regarded as chromosome occupying a unit, all the processes are arranged in a line according to the process number to form a chromosome string, which is shown in Fig. 2 as follows:

TS(1)	TS(2)	...	TS(i)	...	TS(n)

Note: TS(i) are all processes in network

Figure 2. Chromosome structure

(2)Initialization

Initialization process can be completed by randomly generated groups and selecting the appropriate group. However, since the chromosomal of "limited resources, the shortest duration" problem need to meet two constraints: firstly, timing constraints, that is the constraints of the logic relationship between precedence activities and successor activities; secondly, resource constraints, that is to say, daily requirement of each resource in the project period should be no greater than the supply. Therefore, a large number of feasible solutions will be produced by the way of randomly generated groups to initialize.

In view of this characteristic, heuristic algorithm is used to initialize the group in this paper in order to make it meet timing and resource constraints. Based on the initial work numbers of the network, it is supposed that a work has never been selected each time according to the rules from small to big. Firstly, determine the set of preceding activities of the awaiting works, and then identify the position of each work among the chromosome which has been arranged, take the maximum as the position where the work begin to be arranged into. Some random values will be generated between the starting position and the final position where the chromosomes are inserted; the values are the Gene Position of the awaiting work. This process is repeated until all the works are selected and the chromosome meets the timing constraints which come into being. To get chromosome which can meet the resource constraint, such chromosomes are made as the operational object, determine the amount of resources corresponding to each work should be determined, the initial resources list should be formed, and t the actual start time of each process should be adjusted.

(3)Fitness Function

The objective function of the shortest duration with limited resources is $T = \min\{\max\{t_i + d_i \mid i = 1, 2, \cdots, n\}\}$, that is to say the problem is to minimize it. The problem requires shorter duration, greater value of individual fitness; therefore, the objective function cannot be directly used as fitness function, but should be transformed. In this paper, the objective function of "limited resources, the shortest duration "problem is as follows:

$$f(k) = T_{\max} + 1 - T(k) \tag{11}$$

where: $T_{\max}$ is the maximum duration of contemporary chromosome; $T(k)$ is the duration of chromosome *k*; plus 1 is to ensure fitness value being permanently greater than 0.

(4)Genetic Operation

Chromosomes are a combination of ordered genes, so if ordinary crossover and mutation are supplied, it may produce a large number of illegal individuals which do not meet the timing constraints. Therefore, ordered chromosomes need special crossover and mutation[10].

A new crossover method is adopted in this paper which efficiently solves the effective cross-cutting issues of ordered chromosomes. Suppose there are two parent individuals (P1 and P2), as shown in Fig. 3(1), randomly generated α = 4, then crossover operation between the fourth and fifth parent individual is carried out.

First of all, the top four reserved of P1 with P2 is combined to form group a, the top four reserved of P2 with P1 is combined to form group b, which is shown in Fig. 3(2); Then, the works which are the same as the top four of P1(shadow works) is removed from P2, the remaining works of P2 is retained according to work order, the same operation should be implemented on group b, which shown in Fig. 3(3); Finally, the remaining chromosome of each group are spliced, to get two different offspring individuals (C1 and C2) as shown in Fig. 3(4).

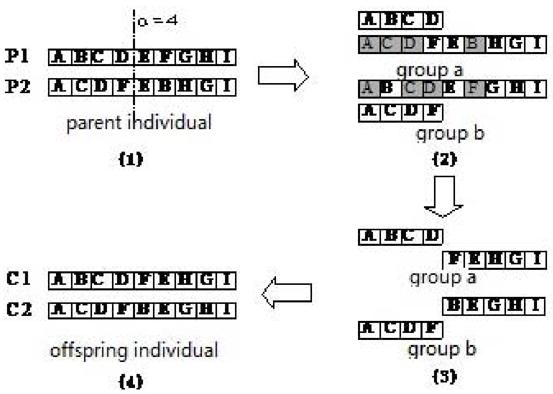

Figure 3. Diagram of ordered chromosome crossover operator

In order to prevent from producing illegal individuals through the common mutation, a centralized search strategy is adopted by mutation operator to design, combine with technology of this area to search improved offspring, so that the chromosome after mutation is still a reasonable chromosome. The main process is as follows: the work is started from the second gene, if it is selected for mutation, the former and latter value should be considered, and then whether there is precedence and successor relation existed between the work represented by mutation-to-be gene and works represented by neighbor genes should be determined; If there is no such relation, exchange the selected gene for one of the precedence or successor genes to form a new chromosome, otherwise no exchange is carried out until go through all of the genes.

For the selection operator, roulette-style method is applied in this paper to select, and the best parent individual of new groups in each generation is preserved, in order to enhance the ability of overcoming the random error of the sample. The specific measure is, if the group does not produce a new individual better than the parent's, remove any one of the new group, and join the best individual of his father to the next generation.

- The Optimization Model of the Resource Leveling with Stationary Duration

(1)Chromosome Structure

Resource optimization based on genetic algorithm mainly selects the chromosome with the largest fitness as parent which generates offspring after crossover. Since the premise of the resource balance is a fixed duration, which means the critical path is invariable, the start times of the critical works are fixed. Therefore, the work of multi-resources equilibrium optimization is to postpone the start times of the certain non-critical works, and make the multi-resources distribution achieve balance[11]. Consequently, the start time of non-critical work TS (i, j) is regarded as the chromosome genes occupying a unit, and the non-critical works are arranged in a line according to the work numbers producing a chromosome string, as shown in Fig. 4.

TS(0,1)	TS(1,2)	…	TS(i,j)	….	TS(n-1,n)

Note: TS(i,j) are non-critical processes

Figure 4. Chromosome structure

Since the premise of the resource balance under the fixed duration, which is the critical processes, remains unchanged, the range of the start times of non-critical processes are relatively fixed, the encoding method is as follows:

$$TS(i,j) = RAN\left[ES(i,j), LS(i,j)\right] \tag{12}$$

where：

$TS(i,j)$——the actual start time of activity(i,j) (chromosome gene)

$ES(i,j)$——earliest starting time of activity (i,j)；

$LS(i,j)$——latest starting time of activity (i,j)；

$RAN(a,b)$ —— arbitrary number randomly selected between *a* and *b*。

(2) Initialization

Before initialization the earliest start time of each process should be obtained, and individual initialization is carried out from right to left -- from the end of the project to the beginning[12]. ES_i is known as the earliest start time of work *i*; S_i is the set of successor activities of process *i*; d_i is the duration of the process *i*; so the genetic value of I, which is also the start time v_i , is:

$$v_i = ES_i + RAN[0, \min\left\{v_k \left| k \in S_i \right.\right\} - ES_i - d_i] \tag{13}$$

Because the whole process is carried out from right to left, the start time v_k of the successor activities of process *i* have been assigned, so this method will not generate illegal schedules. Thus, this approach completely avoids the problem of re-calculating the total float of the follow-up works arising from using it to adjust the start time of the work.

(3) Genetic Operation

Here ordinary one point crossover method is adopted, however, because the start time of a work depends on the start times of its follow-up works, simply crossover operation will generate illegal individuals. Therefore, after crossover it is necessary to check the legitimacy of the individuals to adjust unreasonable individuals[13]. Inspection and adjustment are still carried out from right to left, and the checking formula is as follow:

$$v_i \le \min\{v_k \mid k \in S_i\} - d_i \qquad (14)$$

If the gene values can satisfy this condition, it is reasonable, or need to adjust, and evaluate the gene again according to the formula (13).The mutation is relatively simple. Randomly select a gene locus for a given individual, and then reassign the gene value according to the initialization formula (13).Selection operator is still selected through the roulette-style method to keep the best parent individual.

IV. Engineering Application Analysis

A. Engineering Situation

Longkaikou Hydropower Station, which is the sixth cascade of the planned eight cascade hydropower stations in the middle reach of Jinsha River, is located on Jinsha River in Zhongjiang town Heqing County Yunnan Province. It is next to the Jinanqiao Hydropower Station sited above and Ludila Hydropower Station stood below. The center buildings of the station include concrete gravity diversion dam, riverbed open style spillway, as well as power house at the dam toe of right bank; the installed capacity of the power station is 1800*MW*.

The diversion dam is a RCC gravity dam, its crest elevation is 1303.00*m*, the maximum height is 119.0*m*, and the length of crest axis is 798.0*m*. The dam is divided into 31 blocks from left to right, $1^{\#}\sim 8^{\#}$ are left bank water retaining dam sections for the monoliths length 170.0*m*, of which standard width of 3# ~ 4# are 25.0*m*, standard width of $1^{\#}\sim 2^{\#}$, $5^{\#}\sim 8^{\#}$ are 20*m*; $9^{\#}$ and $13^{\#}$ are left-right flood discharging block with middle level outlet of which the standard width is 24.0*m*; $10^{\#}\sim 12^{\#}$ blocks are the spillway blocks of which the length is 93.0*m*, and the standard width of $10^{\#}$, $12^{\#}$ block are 28.5*m*, standard width of $11^{\#}$ block is 36.0*m*; $14^{\#}\sim 18^{\#}$ blocks are the powerhouse dam section of which the length is 167.0*m*. The standard width of $14^{\#}$ section is 35.0 *m*, standard width of $15^{\#}\sim 18^{\#}$ blocks are 33.0*m*; $19^{\#}$ is sediment discharge bottom outlet section, and the standard width is 20.0*m*; $20^{\#}\sim 31^{\#}$ is the right bank water retaining dam section, its length is 300.0*m*, and the standard width is 25.0*m*.

The powerhouse behind the dam is composed by main powerhouse, upstream auxiliary powerhouse, downstream auxiliary powerhouse, the central control building, boost switching station, and corridor for entering into the plant, etc. The size of the main plant is 237.0*m*×36.5*m*×75.5*m*(length×width×height). Five francis hydroturbine generator sets with unit capacity of 360*MW* are installed totally, setting elevation is 1212.90*m*, and the distance between set spacing is 33.0*m*. Switching station with capacity of 500*KV* using GIS is arranged up the main transformer, the central control building is arranged on the right side of the main transformer, the corridor is on the right of the erecting bay connected with Entrance Road with the elevation 1244.20*m*.

B. Determination of the Initial Network

First of all, the plan should be formulated, then the project is broken down, time parameters should be calculated to determine the critical path. The project can be divided into 86 activities, and after planning, the resources for the plan should be allocated. Basic information of the project plan and the resource allocation is illustrated in Table I and Table II.

TABLE I. The Basic Information of the Activities

Activity	1	2	3	4	5	6
Pre-activity		1	1	1	1	5
Duration	0	335	243	274	273	212
Resource					EE70.4	NC28.7
Activity	7	8	9	10	11	12
Pre-activity	6	1	11,3	5,9	5	5
Duration	61	153	212	1	183	152
Resource		EE10.33	NC11.35			
Activity	13	14	15	16	17	18
Pre-activity	1	13	14	14	14	17
Duration	273	92	153	168	320	396
Resource	EE58.14	NC1.42	NC6.72	NC3.79 RC4.58	RC8.07	RC5.71
Activity	19	20	21	22	23	24
Pre-activity	18	19	18,20	18,20	22	1
Duration	107	197	1	30	151	427
Resource	RC2.76	RC6.05		RC0.53	EE1.66	EE254.99
Activity	25	26	27	28	29	30
Pre-activity	24	25	25	25	28	28
Duration	153	152	198	882	1	1
Resource	NC3.07	NC3.1	NC5.71	RC86.62 NC1.91		
Activity	31	32	33	34	35	36
Pre-activity	28	1	32	33	34	32
Duration	61	395	152	92	31	228
Resource	NC0.8	EE113.22	NC2.48	EE15	NC0.53	RC6.45
Activity	37	38	39	40	41	42
Pre-activity	36	36	36,38	32	30	32
Duration	427	182	577	517	184	487
Resource	RC2.55		RC2.72 NC0.12	RC8.47		RC51.1
Activity	43	44	45	46	47	48
Pre-activity	42	35	44	10	46	46
Duration	365	304	334	398	153	243
Resource	NC25.81	RC12.87	NC6.45	EE83.22	NC2.21	RC18.52

TABLE II. THE BASIC INFORMATION OF THE ACTIVITIES

Activity	49	50	51	52	53	54
Pre-activity	48	48	47	51	51	46
Duration	365	122	365	1	273	608
Resource	NC10.88 RC4.18		RC56.44		RC10.91	RC15.66
Activity	55	56	57	58	59	60
Pre-activity	53	1	56	1	56	56
Duration	275	395	92	730	365	121
Resource		EE66.8	EE17.1	EE297.7	NC 0.71	NC 0.56
Activity	61	62	63	64	65	66
Pre-activity	59	56	62	63	64	65
Duration	335	61	61	90	153	61
Resource	NC 0.68	NC 0.6	NC 0.71		NC0.81	
Activity	67	68	69	70	71	72
Pre-activity	66	55,66,79	56,57	58	70	71
Duration	414	0	913	153	609	334
Resource			NC46.03	NC4.7		NC4.51
Activity	73	74	75	76	77	78
Pre-activity	72	69	69	69	69	76
Duration	243	424	426	426	396	1
Resource		NC1.61	NC1.63	NC1.58	NC1.6	
Activity	79	80	81	82	83	84
Pre-activity	77	57	71	66,74	66,75	66,76
Duration	1	365	304	395	396	396
Resource						
Activity	85	86	*NOTE: EE means earth-rock excavation; NC means normal concrete; RC means roller-compacted concrete.*			
Pre-activity	66,77	85				
Duration	395	0				
Resource						

C. Analysis of Resource Allocation Optimization

- Optimal Analysis on the Shortest Duration with Limited Resource

(1)Constraint Conditions

According to the various resource conditions of Longkaikou hydropower station, the maximum construction intensity of the main resources are designed as follows: the maximum intensity of earth-rock excavation is $55\times10^4 m^3$/month; normal concrete pouring is $8\times10^4 m^3$/month; as well as roller-compacted concrete pouring is $16\times10^4 m^3$/month. In addition, the network also includes the processes under some special time constraints, and the basic information is given in Table III.

TABLE III. THE SPECIAL TIME CONSTRAINTS OF PROCESSES

Activity	Limited type and the time	Activity	Limited type and the time
3	LS September 1,2006	30	LF May 31,2009
6	LF October 31,2007	52	LF May 31,2009
10	LS December 5,2007	68	LF December 31,2010
21	LF May 31,2010	78	LF April 1,2010
29	LF May 31,2008	79	LF August 1,2010

(2)Parameters Setting

In order to prove the efficiencyof the optimization model, we adopt the optimization model with genetic algorithm to optimize the project's resource allocation. The parameters are set as follows: population size(*popsize*)=50, crossover probability(p_c)=0.6, mutation probability(p_m)=0.01, the maximum evolution generation=800.

(3)Optimization Results

The optimization results of the shortest duration with limited resources can be shown in Fig. 5, 6.

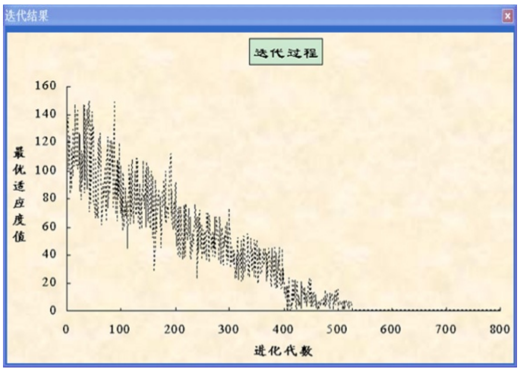

Figure 5. The optimal fitness value changing curve of each generation

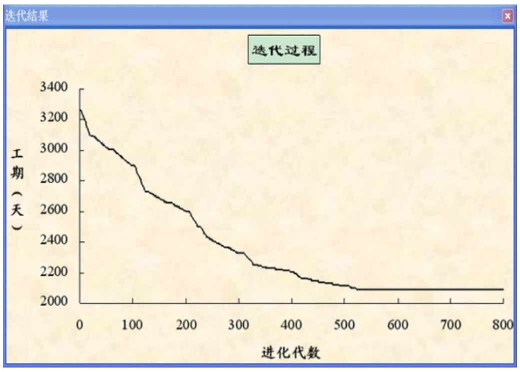

Figure 6. Convergence curve of the duration

As can be seen from Fig. 5, at the beginning of optimization, optimal fitness value is in a fluctuant situation, and it has large amplitude. The defined fitness function $f(k)=T_{\max}+1-T(k)$ indicates that there is a certain difference between the best and the worst individual in each generation. With further evolution, the fluctuation of the optimal fitness value is becoming smaller, which shows the difference between the best and the worst individual is getting smaller and the optimal fitness value is convergence. When the iteration evolves to 527^{th} generation, the fitness value will not change (becoming a constant 1), then there is no difference between the best and the worst individual ($T_{\max}=T(k)=T_{\min}$), which indicates that it has converged to the best.

As can be seen from Fig. 6, the duration of the first generation is the largest which is 107 months (3257 days). When it evolves to 527^{th} generation, the duration has remained stable as 69 months (2092 days). It indicates that the optimization has reached the global optimal solution. Therefore, according to optimization model with genetic algorithm, the total duration of the project is 69 months (2092 days).

The start times of the best individuals calculated by the optimization model are shown in Table IV.

TABLE IV. THE ACTUAL START TIME CALCULATED BY THE OPTIMIZATION MODEL OF THE SHORTEST DURATION WITH LIMITED RESOURCES

Activity	Start Time	Activity	Start Time
1	July 1, 2006	44	October 15, 2008
2	July 2, 2006	45	October 1, 2009
3	September 1, 2006	46	March 1, 2008
4	July 2, 2006	47	September 1, 2008
5	August 1, 2006	48	December 10, 2008
6	March 1, 2007	49	September 1, 2009
7	October 1, 2007	50	October 1, 2009
8	August 1, 2006	51	November 1, 2008
9	October 1, 2006	52	May 31, 2009
10	December 5, 2007	53	October 1, 2009
11	October 1, 2007	54	October 1, 2008
12	November 1, 2007	55	April 1, 2010
13	August 1, 2006	56	September 1, 2006
14	June 1, 2007	57	June 1, 2008
15	June 16, 2007	58	September 1, 2006
16	May 16, 2007	59	October 1, 2007
17	July 16, 2007	60	February 1, 2008
18	May 1, 2008	61	March 1, 2009
19	October 1, 2009	62	September 1, 2008
20	January 16, 2010	63	January 1, 2009
21	May 31, 2010	64	January 1, 2009
22	August 1, 2010	65	February 1, 2009
23	December 1, 2010	66	September 1, 2009
24	December 1, 2006	67	December 1, 2009
25	May 1, 2007	68	December 31, 2010
26	October 1, 2007	69	November 1, 2007
27	November 16, 2007	70	August 1, 2007
28	January 1, 2008	71	February 15, 2008
29	May 31, 2008	72	November 5, 2009
30	May 31, 2009	73	October 1, 2009
31	June 1, 2010	74	January 15, 2009
32	November 1, 2006	75	October 1, 2008
33	December 1, 2008	76	December 15, 2008
34	May 1, 2008	77	July 1, 2009
35	August 1, 2008	78	April 1, 2010
36	February 1, 2008	79	August 1, 2010
37	November 1, 2008	80	January 1, 2009
38	October 1, 2008	81	December 15, 2009
39	November 1, 2008	82	April 11, 2010
40	January 1, 2008	83	August 1, 2010
41	May 1, 2009	84	December 1, 2010
42	March 15, 2008	85	April 1, 2011
43	July 1, 2009	86	March 23, 2012

- Optimal Analysis on the Resource Leveling with Stationary Duration

(1)Constraint Conditions

The optimization of resource leveling with stationary duration is carried out under the constraint condition of 69 months(2092 days) calculated by the optimization model of the shortest duration with limited resource. Under the constant condition of 69 months (2092 days), in order to make resource consumption equilibrium, wen can adjust start time and completion time of each activity on non-critical path by using the total float time.

(2)Parameters Setting

In this optimization model, the relative parameters can be set as follows: population size(*popsize*) = 50, crossover probability(p_c) = 0.6, mutation probability(p_m) = 0.01, the maximum evolution generation= 500.

(3)Optimization Results

The optimization results of the resource leveling with stationary duration can be shown in Fig. 7, 8.

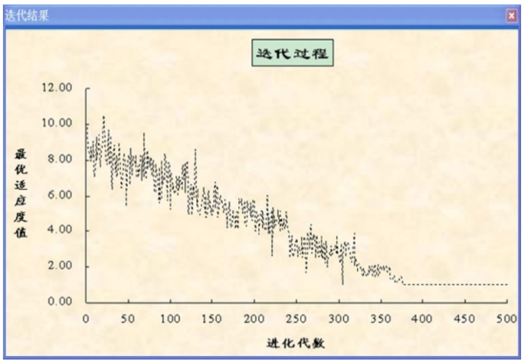

Figure 7. The optimal fitness value changing curve of each generation

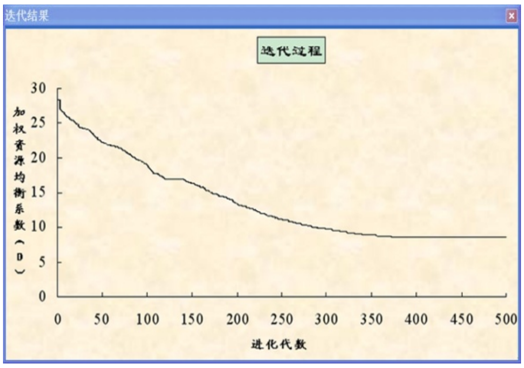

Figure 8. Convergence curve of the weighted resource leveling coefficient

As can be seen from Fig. 7, at the beginning of optimization, optimal fitness value is in a fluctuant situation, and it has large amplitude. With further evolution, the fluctuation of the optimal fitness value is becoming smaller. When the iteration evolves to 376th generation, the fitness value is becoming a constant 1, then there is no difference between the best and the worst individual, which indicates that it has converged to the best.

As can be seen from Fig. 8, the first weighted resource leveling coefficient is maximal(28.37). Along with evolution, it shows a decreasing trend. After it evolves to 367th generation, the weighted coefficient remains stable and converges to 8.60. It indicates that the optimization has reached the global optimal solution. Therefore, the optimal weighted resource leveling coefficient is 8.60.

The results of the resource optimization are shown in Fig. 9, 10, 11.

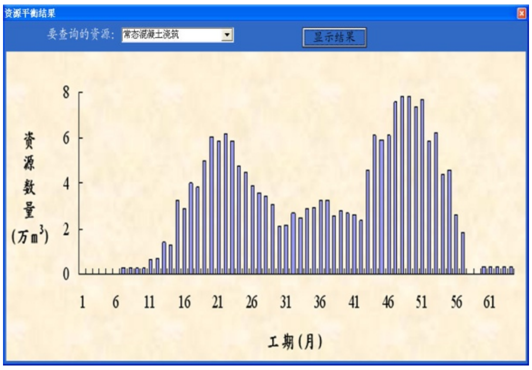

Figure 9. Optimization result of earth-rock excavation

Figure 10. Optimization result of normal concrete pouring

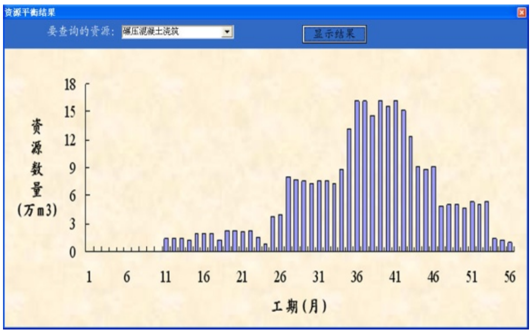

Figure 11. Optimization result of roller-compacted concrete pouring

After optimizing by the genetic algorithm, the start time of each activity on critical path has not changed as their free float is 0, but the actual start time of each activity on non-critical path has been optimized, and the optimization results are shown in Table V.

V. CONCLUSIONS

This paper analyzes the problem of optimization for resource allocation and leveling, such as shortest duration with limited resource and resource leveling with stationary duration. Based on that, the mathematical model of resource allocation and leveling problem is set up and a GA-based solution is presented. For specified resource limits, the GA-based approach can produce the

TABLE V. THE ACTUAL START TIME CALCULATED BY THE OPTIMIZATION MODEL OF THE RESOURCE LEVELING WITH STATIONARY DURATION

Activity	Start Time	Activity	Start Time
1	July 1, 2006	44	October 1, 2008
2	July 2, 2006	45	August 1, 2009
3	September 1, 2006	46	February 1, 2008
4	July 2, 2006	47	September 1, 2008
5	August 1, 2006	48	December 1, 2008
6	March 1,2007	49	August 1, 2009
7	October 1, 2007	50	September 1, 2009
8	August 1, 2006	51	November 1, 2008
9	November 1, 2006	52	May 31, 2009
10	December 5, 2007	53	November 1, 2009
11	October 1, 2007	54	October 1, 2008
12	November 1, 2007	55	April 1, 2010
13	August 1, 2006	56	September 1, 2006
14	May 1, 2007	57	May 1, 2008
15	June 16, 2007	58	September 1, 2006
16	June 16, 2007	59	October 1, 2007
17	June 16, 2007	60	February 1, 2008
18	May 1, 2008	61	October 1, 2008
19	November 1, 2009	62	September 1, 2008
20	February 16, 2010	63	November 1, 2008
21	May 31, 2010	64	January 1, 2009
22	September 1, 2010	65	April 1, 2009
23	December 1, 2010	66	September 1, 2009
24	December 1,2006	67	November 1, 2009
25	May 1, 2007	68	December 31, 2010
26	October 1, 2007	69	October 1, 2007
27	November 16, 2007	70	August 1, 2007
28	January 1, 2008	71	January 1, 2008
29	May 31, 2008	72	November 1, 2009
30	May 31, 2009	73	October 1, 2009
31	June 1, 2010	74	January 1, 2009
32	November 1, 2006	75	October 1, 2008
33	December 1, 2007	76	February 1, 2009
34	May 1, 2008	77	July 1, 2009
35	August 1, 2008	78	April 1, 2010
36	February 16, 2008	79	August 1, 2010
37	December 1, 2008	80	January 1, 2009
38	October 1, 2008	81	January 1, 2010
39	December 1, 2008	82	April 11, 2010
40	January 1, 2008	83	August 1, 2010
41	May 1, 2009	84	December 1, 2010
42	March 1,2008	85	April 1, 2011
43	July 1, 2009	86	March 23, 2012

optimum project duration quikly. Moreover, the model is capable of handing a wide range of project size including large construction projects involving a larger number of activities. It can not only compress project duration in maximum, but also reasonably arrange activity starting time in uncritical path, and adjust the order of resource in different activities and to make resource consumption be in equilibrium state. Finally, the mathematical model of resource allocation and leveling problem is applied in an engineering project. The result shows that Genetic Algorithm can solve relative problems of resource allocation optimization for large-scale project very well and will be widely used in project optimization.

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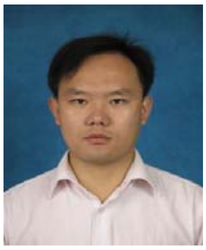

Jian-wen Huang was born in China in 1977. He got his B.S. in engineering management from Wuhan University of Hydraulic and Electric Engineering in 2000, and M.S. in hydraulic structure engineering from China Three Gorges University in 2005. He also received his Ph.D. in hydraulic structure engineering from Wuhan University in 2008. He is now working as assistant professor at College of Hydraulic & Environmental Engineering, China Three Gorges University(CTGU). From 2000 to 2010, he has researched in College of Hydraulic & Environmental Engineering, China Three Gorges University(CTGU) on the topics like constrution managment of hydroelectric engineering, construction organization and system simulation of hydroelectric engineering; technical and economic management theory and its application and so on. He has published over 22 papers in related journals and international conferences. His interests include optimization and decision-making, construction project management, risk analysis in project management and so on.

Xing-xia Wang was born in China in 1980, and she is now major in Wuhan University in wuhan in China for her Ph.D. Her research interests are slope deformation analysis, slope stability evaluation, thoery of unloading rock mass for jiont rock mass and its appliation, and constrution managment of hydroelectric engineering.

Rui Chen was born in China in 1988, and she is now studying at China Three Gorges University majoring in Management Science and Engineering for her Master's degree. Her research interests are constitution organization and management and risk analysis in project management.