GA-Based Equipment Support Resource Leveling Optimization

J.C. WANG
The Academy of Equipment, Beijing, China

M. WEI
AVIC Computing Technique Research Institute, Xi'an, Shaanxi, China

Y.F. SHI
The Academy of Equipment, Beijing, China

ABSTRACT: Equipment support decision-making is the important foundation to effectively organize equipment support. Equipment support is dependent on various support resources. The less the fluctuation of resource requirement during the project, the more advantageous the organization and carrying out of equipment support tasks in line with the predetermined schedule. Resource leveling optimization is the basic approach to achieve resource requirement leveling. Traditional exact and heuristic algorithms are inefficient in solving the problems even of medium scale. Genetic algorithm with repairing operator is utilized to overcome drawbacks of traditional methods. The performance of the adopted method is demonstrated by obtaining the optimal or near-optimal solutions to the simulated problems.
KEYWORD: Resource leveling; Equipment support; Genetic algorithm; Network planning; Optimization

1 INTRODUCTION

Equipment support is dependent on various support resources, and the less the fluctuation of resource requirement during the project, the more advantageous the organization and carrying out of equipment support tasks in line with the predetermined schedule. Equipment support decision-making is the important foundation to effectively organize equipment support. How to properly arrange the activities in a project belongs to resource leveling optimization problem (Leu et al. 2000). The objective of resource leveling optimization is to reduce the fluctuations in resource usage as much as possible over the project duration by properly arranging the activities in the project. Being of NP-hard, the resource leveling problem presents too big a search space for exhaustive enumeration to attain the optimum even for ones of medium scales. Mathematical models such as integer linear programing, dynamic programming and branch and bound, etc. have been traditionally used to solve the problem of this kind, but none of them is computationally effective to deal with the bottleneck of combinational explosion (Ahmed & Neil 2004). Genetic algorithm (GA) is a global stochastically searching heuristic (Zhou & Sun 1999), which is capable of tackling the combinational optimization problems originated in various fields.

Genetic algorithm with repairing operator is used to find the optimal or near-optimal solution to equipment support resource leveling problem. The algorithm can overcome the shortcomings of the traditional methods mentioned above. GA solutions to several simulated examples demonstrate the effectiveness of the adopted algorithm.

2 FORMULATION

An equipment support project can be schematically expressed using activity-on-arrow network as shown in Figure 1. There are 9 activities and 6 nodes in the project. All activities maintain deterministic logic relation, and there is no more than one activity between each pair of nodes. (i, j) denotes an activity between the pair of nodes i and j. For example, (4, 5) denotes activity “G”. The set of all activities of the project is denoted by W, and that of all front closely activities of an activity (i, j) is denoted by $F(i, j)$.

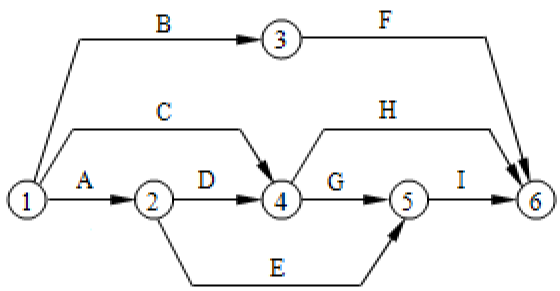

Figure 1. Activity-on-arrow network of an equipment support project with 9 activities and 6 nodes.

The resource leveling problem of a project can then be described as follows: given that the duration time of activity (i, j), $D_{(i,\ j)}$ ($\forall$ (i, j)$\in W$), and the resource requirement per unit time, $r^0{}_{(i,\ j)}$ ($\forall$ (i, j)$\in W$); the total project duration, T; the resource requirement quantity of the project at moment t, $R(t)$; the earliest start time, the latest start time, and the actual start time of activity (i, j), $t_{ES}(i, j)$, $t_{LS}(i, j)$, and $t_{AS}(i, j)$, respectively. During the process of the optimization, the logical relation among activities should not be changed, an activity not be interrupted once started, and the total project duration be fixed. The objective for resource leveling is to find the actual start time of each activity in the project such that the variance of the resource requirements over the project period is minimized. The model is formulated as an optimization problem as in formula (1a) subject to conditions in formula (1b).

$$\text{Minimize}\quad \sigma^2 = \frac{1}{T}\sum_{i=1}^{T} R^2(t) - R_m{}^2 \tag{1a}$$

Subject to:

$$\begin{cases} R(t) = \sum_{(i,\ j)} r_{(i,\ j)}(t),\ \ (i, j) \in W \\ r_{(i,\ j)}(t) = \begin{cases} r^0_{(i,\ j)}, when\ t_{AS}(i, j) \le t \le t_{AS}(i, j) + D_{(i,\ j)} \\ 0, when\ t \le t_{AS}(i, j)\ or\ t \ge t_{AS}(i, j) + D_{(i,\ j)} \end{cases} \\ t_{AS}(h, i) + D_{(h,\ i)} \le t_{AS}(i, j), \forall (h, i) \in F(i, j) \\ t_{ES}(i, j) \le t_{AS}(i, j) \le t_{LS}(i, j) \end{cases} \tag{1b}$$

in which, R_m is the mean of $R(t)$ over the project duration; (h, i)$\in F(i, j)$ is one of the front closely activities of the activity (i, j).

3 GA WITH REPAIRING OPERATOR

GA is essentially an iteration procedure that operates on sets of decision variables. For GA solution, gene structure must be carefully designed first. A chromosome has N genes, each corresponding to a variable, in which the start time of an activity to be planned is stored. Roulette wheel selection, single point crossover, and random mutation are adopted as the selection, crossover, and mutation operators, respectively. Although the planned start time of activity (i, j), $t_{AS}(i, j)$, is feasible at the beginning of a generation, being within its lower and upper bounds, $t_{ES}(i, j)$ and $t_{LS}(i, j)$ respectively, and satisfying the logic relation as well, it still has certain possibility to be degraded into nonfeasible solution, which is resulted from the genetic operations. If it happened, the repairing operator is used to renovate the actual start time of activity (i, j), $t_{AS}(i, j)$. The repairing operator is activated whenever the repairing criterion is checked at right time and the inequality below holds, as stated in Formula (2). Repairing operator is executed by enforcing the gene value, equal to the maximum of the actual finish times of all front closely activities for activity (i, j).

$$t_{AS}(h, i) + D_{(h,\ i)} > t_{AS}(i, j), \forall (h, i) \in F(i, j) \tag{2}$$

The essence of project duration fixed resource leveling is to make the resource requirement least fluctuant by properly arranging the actual start time of all activities in the project. The less fluctuated the quantity, the fitter the chromosome. If the objective function $g(\boldsymbol{t}_{AS})$ is defined as in Formula (3):

$$g(\boldsymbol{t}_{AS}) = \sigma^2 \tag{3}$$

the fitness function $f(\boldsymbol{t}_{AS})$ can be as in Formulas (4) and (5), termed as relative fitness function and absolute fitness function, respectively.

$$f(\boldsymbol{t}_{AS}) = \frac{g_{\max} - g(\boldsymbol{t}_{AS}) + \varepsilon}{g_{\max} - g_{\min} + \varepsilon} \tag{4}$$

$$f(\boldsymbol{t}_{AS}) = G_{\max} - g(\boldsymbol{t}_{AS}) \tag{5}$$

For small scale problem, both of them can be used to evaluate the chromosome, whereas the absolute one is preferred to evaluate chromosomes of medium scale problem or even those of large scale problem.

4 SIMULATION RESULTS

Two instances are solved using GA with repairing operator as described above, one for problem of small scale and the other for that of medium scale. The algorithm is implemented with Matlab language.

4.1 *Problem of small scale*

The graph of the problem is as shown in Figure 1. $D_{(i,\ j)}$, $F(i, j)$ and $r^0{}_{(i,\ j)}$ are given in Table 1. The earliest start time $t_{ES}(i, j)$ and the latest start time $t_{LS}(i, j)$ are obtained using critical path method (CPM) and listed in the last two columns in Table 1. The project duration T is 14, R_m = 11.85714286. The parameters for GA are *popSize* = 30, *chromLen* = 9, *PC* = 0.65, *PM* = [0.25 0.20], *maxGen* = 20. The relative fitness function is adopted. The GA program is run randomly 10 times, and the solutions are given in Table 2. The first 10 exact solutions are obtained but not given here using exhaustive enumeration method. Seven out of ten solutions have attained the exact ones of the problem, and they are not the same, which shows the capability of the GA. Due to Formula (4) utilized, it is evident from Figure 2 that the minimum objective value approaches to the exact one oscillating within small range within several generations though the Elitist substitution strategy is utilized, which is contributed to the small scale of the problem. It may be rather difficult for the minimum objective value to wave its way in approaching the exact one in solution to problems with large or even medium scales if Formula (4) was adopted. From GA solutions in Table 2, the excellent properties such as being probabilistically converged to one of multiple global optimums are observed.

Table 1. Parameters for problem of small scale and CPM results.

(i, j)	Nodes	$F(i,j)$	$D(i, j)$	$r^0_{(i, j)}$	$t_{ES}(i, j)$	$t_{LS}(i, j)$
A	1, 2	-	2	6	0	0
B	1, 3	-	4	3	0	3
C	1, 4	-	5	5	0	1
D	2, 4	A	4	4	2	2
E	2, 5	A	3	7	2	9
F	3, 6	B	7	4	4	7
G	4, 5	C, D	6	5	6	6
H	4, 6	C, D	4	3	6	10
I	5, 6	E, G	2	5	12	12

Table 2. 10 random GA solutions to the problem of small scale.

n	$g(\boldsymbol{t}_{AS})$	GA solution								
		B	C	E	F	H	A	D	G	I
1	2.83673469	2	0	5	7	8	0	2	6	12
2	2.83673469	2	0	5	7	10	0	2	6	12
3	3.69387755	0	0	5	7	8	0	2	6	12
4	2.83673469	1	0	5	7	9	0	2	6	12
5	3.69387755	0	0	4	7	7	0	2	6	12
6	2.83673469	1	0	5	7	8	0	2	6	12
7	2.83673469	2	0	5	7	10	0	2	6	12
8	2.83673469	2	0	5	7	8	0	2	6	12
9	3.69387755	0	0	4	7	7	0	2	6	12
10	2.83673469	1	0	5	7	8	0	2	6	12

4.2 *Problem of medium scale*

The problem of medium scale is schematically shown in Figure 3. The duration and the resource requirement quantity per unit time of activity (i, j), $D_{(i, j)}$ and $r^0_{(i, j)}$, are given in Table 3. The earliest start time $t_{ES}(i, j)$ and the latest start time $t_{LS}(i, j)$ are also listed in the last two columns in Table 3. The project duration T is 23, R_m = 18.39130435. Four GA solutions to the problem with 17 activities (19 decision variables instead) is given in Table 4, the scheduled actual start times for 17 activities are plotted in Figure 4, and the resource requirement per unit time is shown in Figure 5.

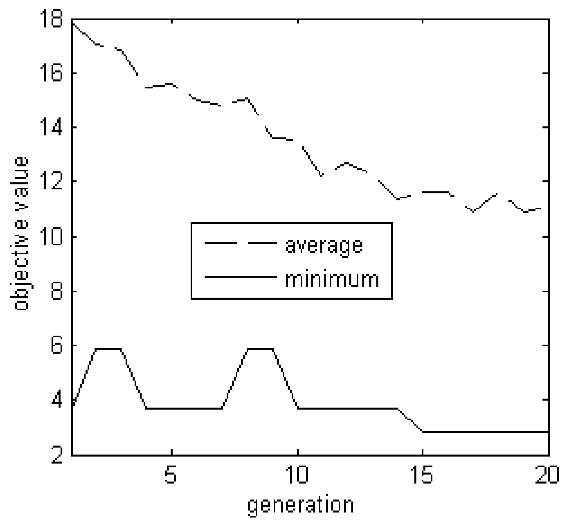

Figure 2. Objective values vs. generations curve.

Table 3. Parameters for problem of medium scale and the CPM results.

(i, j)	Nodes	$F(i, j)$	$D(i, j)$	$r^0_{(i, j)}$	$t_{ES}(i, j)$	$t_{LS}(i, j)$
A	1, 2		2	10	0	2
B	2, 4	A	3	5	2	6
C1	4, 7	B, E, K	6	9	7	9
C2	4, 6	B, E, K	5	1	7	10
C3	4, 8	B, E, K	3	4	7	12
D	4, 12	B, E, K	5	9	7	18
E	2, 3	A	5	1	2	4
F	3, 5	E	3	2	7	16
G	5, 12	F	4	3	10	19
H1	9, 10	C1, C2, C3	2	2	13	16
H2	8, 10	C1, C2, C3	3	7	13	15
I	8, 11	C1, C2, C3	6	3	13	15
J	11, 12	I	2	2	19	21
K	1, 4		6	1	0	3
L	2, 8	A	7	8	2	8
M	1, 10		18	5	0	0
N	10, 12	M, H1, H2	5	10	18	18

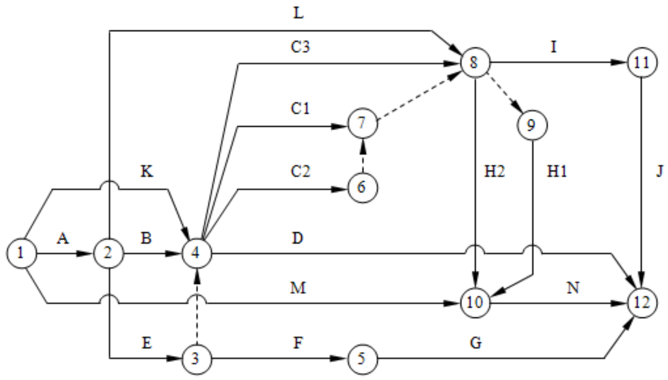

Figure 3. Equivalent activity-on-arrow network of an equipment support project with 17 activities and 12 nodes.

Table 4. Four GA solutions to the problem with 17 activities.

$g(\boldsymbol{t}_{AS})$	Activities																
	A	B	C1	C2	C3	D	E	F	G	H1	H2	I	J	K	L	M	N
4.67296786	0	4	9	10	7	18	2	10	13	16	15	15	21	0	2	0	18
5.02079395	0	5	9	10	8	18	2	11	14	16	15	15	21	0	2	0	18
5.19470699	0	5	9	8	11	18	2	8	14	16	15	15	21	0	2	0	18
5.54253308	0	6	9	10	9	18	2	11	14	15	15	15	21	0	2	0	18

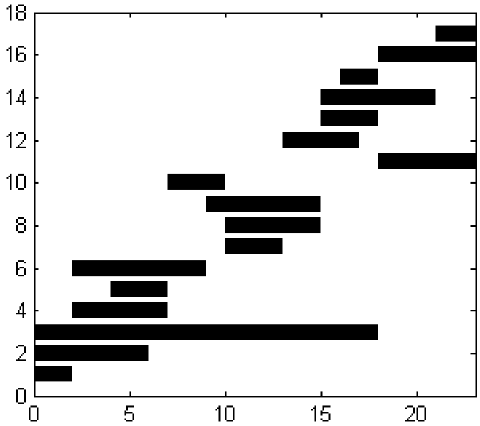

Figure 4. The scheduled actual start times during the period of the problem with 17 activities.

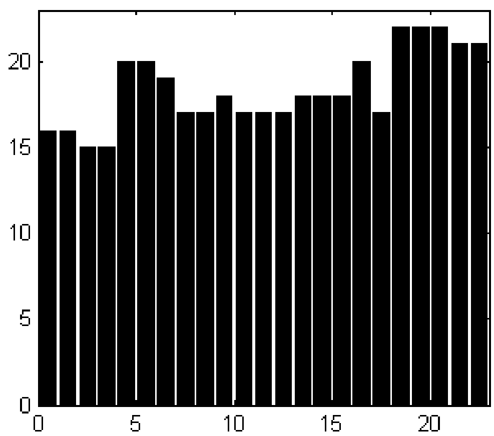

Figure 5. The quantity of resource requirement per unit time during the period of the problem with 17 activities.

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