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OPTIMIZATION OF RESOURCE ALLOCATION IN CONSTRUCTION USING GENETIC ALGORITHMS

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Abstract:

Resources for activities in construction project are limited in the real-life world. So resource allocation is of great importance to construction project management to avoid the waste and shortage of resources on a construction project. This paper presents a genetic algorithm model for resource allocation. Compared to the traditional crossover methods, the proposed model develops a new crossover operator to avoid producing illegal chromosomes. The model can effectively provide the optimum solution to resource allocation problem. An illustrative example is presented to demonstrate the performance of the proposed approach.

Keywords:

Resource allocation; genetic algorithms; optimization

1. Introduction

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 [1]. Mathematical methods, however, are not computationally tractable for any real-life project, which is reasonable in size, rendering them impractical [2,3,4]. Later attempts used heuristic methods to overcome the problem of combinatorial explosion, but these heuristic models were problem dependent, so that their rules of thumb could not be equally applied to all construction cases [5]. In addition, they can not guarantee optimum solutions [6].

In this paper, a new approach, employing the use of genetic algorithms, is developed to overcome those drawbacks and searches for the optimum solutions of a single project with multiple resources limited by using a serial of mode of allocation with the objective of minimizing project duration between resource availability and utilization. The test example will be presented to illustrate the performance of the GA-based approach.

2. Problem description

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. Activity duration is usually measured in integral increments of time called planning units. The normal duration of an activity refers to the time required to complete that activity under normal circumstances. For some activities, it is possible to reduce the duration of an activity below the normal duration. This is done through crashing, which can reduce activity duration. So, the crash duration refers to the shortest time possible to complete an activity when cashing is performed. The resource allocation problem starts off with the assumption that resource availability is constrained to some maximum value and the objective is to allocate the available resources to project activities in an attempt to find the shortest project duration.

The logic of resource allocation optimization is expressed mathematically as follows:

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

subject to: $$t_j - t_i - d_i \ge 0 \quad j \in S_i \quad (2)$$

$$\sum_{t_j \in A_{t_i}} r_{dik} \le b_k \quad (k = 1,2,\dots,m) \quad (3)$$

$$M_i \le d_i \le N_i \quad (d_i, t_i \ge 0, i = 1,2,...,n) \quad (4)$$

where T= project duration; $t_{i,j}$= starting date of activity i, j; d_i = duration of activity i; A_{t_i} = set of ongoing activities at date t_i; b_k = resource limit of kth resource; M_i = crash duration of activity i; N_i = normal duration of activity i.

Eq. (1) indicates the computation for project duration. Eq. (2) states that the difference in occurrence times of two connected nodes must be at least as great as the duration of the connecting activity. Eq.(3) states that the resource utilized can not exceed available resources. Eq. (4) restricts each activity time to the interval between normal and crash time.

3. Resource allocation optimization with genetic algorithms

Based upon the concept of GAs and the mathematical model described previously, the following sections present the technique of the GAs for solving resource allocation optimization problem.

3.1. Chromosome Representation

The main work of resource-constrained allocation is to deciding the order of scheduling the individual activity, therefore, resource allocation belongs to one type of sequencing problem. In this study, each chromosome in the population stands for a possible sequence of activities and each gene value in the chromosome represents an activity identification (or name). An activity in a lower position has a higher priority of getting resources. For example, in Figure.1, activity C has higher priority than activity B.

1	2	3	4	5	6	7	8	9
A	C	B	D	E	F	H	G	I

Legend: x → gene position

$\boxed{y}$ → gene value (activity name)

Figure.1 Chromosome structure for resource-constrained allocation

3.2. Determination of the fitness function

As shown in Fig.(1), the project duration is defined as the objective of resource allocation optimization problems. Since genetic algorithms were traditionally designed to solve problems of seeking maximums, it needs to formulate the problem of interest (i.e. seeking minimum project duration) into a problem of seeking maximum, therefore, the fitness function in this study is defined as follows:

$$f(i) = F - T(i) \tag{5}$$

Where, $f(i)$ = fitness value of chromosome i; F = a beforehand prescribed number which is big enough to ensure the value of $f(i)$ always bigger than zero; $T(i)$ = the project duration defined by chromosome i.

3.3. Genetic Operators

3.3.1. Selection strategy

The main selection strategy in the genetic algorithms for multi-resource leveling problem is the Roulette wheel method [7,8] combined with Elitist method [7,8] to improve selection efficiency. According to the Roulette wheel principle, the selection probability for a chromosome k is proportional to the ratio of $f_k \Big/ \sum_{j=1}^{popsize} f_i$, where f_k = the fitness value of the chromosome k. Moreover, by using Elitist method, the best chromosome of current generation can be preserved into the next generation.

3.3.2. Crossover operator

Because there generally exist some precedence relationships among activities in a scheduling problem, several crossover operators intensively used in sequencing problems will generate illegal chromosomes, which can not maintain the precedence relationships. To overcome this drawback, a new crossover operator is developed in this paper.

Take two parent chromosomes in Fig.2 as an example, assuming that these two chromosomes are the legal ones which stand for two possible activity sequences of a schedule network. The procedure of the new crossover operator is performed as follows:

Step1. Select one position along the first chromosome at random as the crossover site, for example the 4th position in the Parent 1.

Step2. Select the left substring defined by the crossover site from Parent1, say A-B-C-D, as the left substring of Offspring 1.

Step3. To each gene of Parent2, perform the operation from left to right as follows: select a gene of Parent2 in sequence, and search the Offspring1, if no find the same gene in Offspring1, then add the selection gene into the last position of Offspring1, otherwise, skip the selection of the gene in Parent2, as shown in Step3 in Figure.2.

Step4. Repeat the Step3 until the offspring1 is completed. With the same steps, the second offspring is produced from the same parents.

(1) Selection of crossover site.

Crossover point

A	B	C	D	E	F	G	H	I	Parent 1
A	C	D	F	E	B	H	G	I	Parent 2

(2) Generating left substring for offspring1

A	B	C	D	E	F	G	H	I	Parent 1
A	B	C	D						Offspring1
A	C	D	F	E	B	H	G	I	Parent 2

(3) Selection of genes and insertion of genes into offspring string.

A	B	C	D	E	F	G	H	I	Parent 1
A	B	C	D	F					Offspring1
A	C	D	F	E	B	H	G	I	Parent 2

(4) Result of crossover operations.

A	B	C	D	E	F	G	H	I	Parent 1
A	B	C	D	F	E	H	G	I	Offspring1
A	C	D	F	E	B	H	G	I	Parent 2

Figure.2 Crossover operation

The way of crossover operation mentioned above, can not only avoid the problem of gene duplication after the crossover, but also take account of activity precedence relationships when selecting genes from parents into offspring strings.

3.3.3. Mutation operator

The mutation operator used in the study is uniform mutation [9]. Uniform mutation replaces a gene with a randomly selected gene within a specified range. Let a chromosome to be mutated by is $A = [a_1, a_2, a_3, \ldots, a_n]$. A random number $k \in [1, n]$ is first selected based on a predefined mutation rate. An offspring $A' = [a_1, a_2, a_3, \ldots, a'_k, \ldots, a_n]$ is then produced. The value of a'_k is selected within the specified range consisted of all the activities which have the same priority as the activity a_k.

4. Illustrative example

As an example, a critical path network (CPM) [10] shown in Figure.3 describes the precedence relationships of the project, which consists of 10 activities (Label A—J). Each activity has two fixed resource requirements. Daily resource limits for resource 1 and 2 are 10 and 8, respectively. The case study data including activities' resource requirements, daily resource limits and duration is presented in Table1.

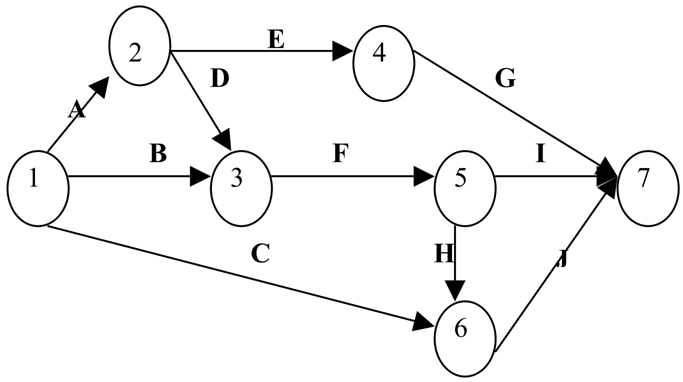

Figure.3 Example project CPM network

Table1. Case study data

Activity	Duration	Predecessors	Res.1 Requ.	Res.2 Requ.
A	8	—	4	3
B	3	—	4	5
C	5	—	6	4
D	2	A	7	6
E	4	A	2	3
F	4	B,D	6	7
G	6	E	3	2
H	6	F	8	6
I	4	F	2	6
J	10	C,H	5	5

(Note: Res.1 Requ., Res.2 Requ.= Resource 1 and Resource 2 requirements per day, respectively).

Following some suggestions for GA operators [7], the initial population, crossover rate (P_c), mutation rate (P_m) and iteration times, are defined as 40, 0.8, 0.01, and 50 respectively, and parameter F in Eq.5 is defined as 50. Figure.4 shows the convergence process of maximum and average fitness value in each generation.

It is clearly found in Fig.4 that, at the 25th generation, the GA approach defined previously has searched the optimum chromosome (solution), which corresponds to the minimum project duration, which is 34 days.

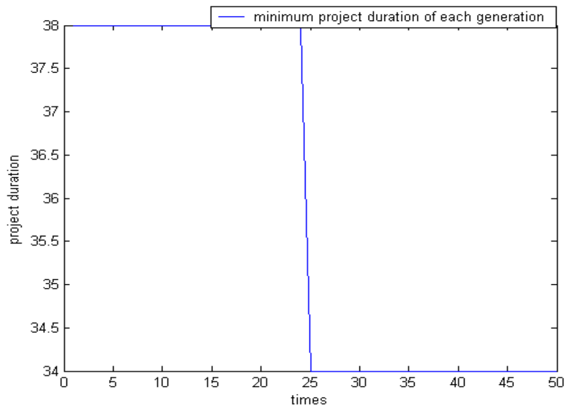

Figure.4 Convergence histories of resource leveling

The original situation of resource 1 and resource 2 allocation are shown in Figure.5 and Figure.6, respectively. The histogram based on GA-approach for resource 1 and 2 are shown in Figure.7 and Figure.8, respectively.

Figure.5 Histogram for resource1 allocation before optimization

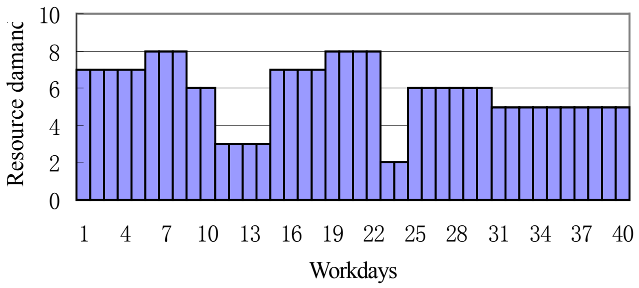

Figure.6 Histogram for resource2 allocation before optimization

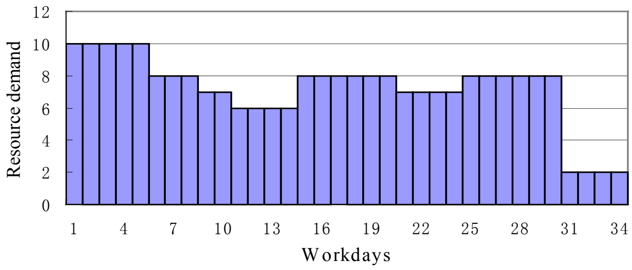

Figure.7 Histogram for resource1 allocation after optimization

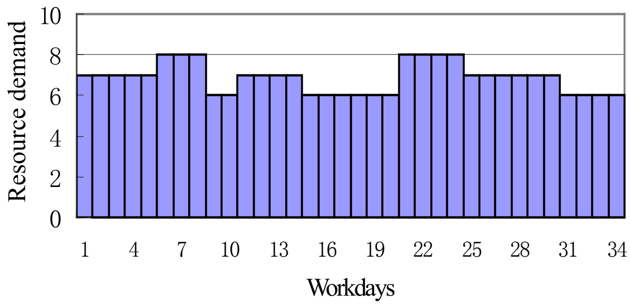

Figure.8 Histogram for resource2 allocation after optimization

It is observed that after using GA-based approach, the project duration reduced to 34 days, from the original project duration 40 days. On the other hand, before GA-based optimizing, the resource 1 requirement varies from a minimum value of 2 to a maximum value of 10 as shown in Fig.5, and resource 2 requirement varies from a minimum value of 2 to a maximum value of 10 as shown in Fig.6. After GA-based optimization, the resource 1 requirement varies from a minimum value of 2 to a maximum value of 10 as shown in Fig.7, and resource 2 requirement varies from a minimum value of 6 to a maximum value of 8 as shown in Fig.8. Therefore, it is not only that the project duration is reduced, but also that the limited resource is sufficiently utilized, which has great significance to construction project management.

5. Conclusions

A GA-based resource allocation model for construction projects is presented in this paper. For specified resource limits, the GA-based approach can produce the optimum project duration and complements the traditional CPM approach as well. Moreover, the model is capable of handing a wide range of project size including large construction projects involving a larger number of activities. Finally, surveys of combination of the GA-based approach with other scheduling problems, such as time/cost trade-off and resource leveling, may be of importance to researchers.

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