A GENETIC ALGORITHM FOR RESOURCE LEVELING OF CONSTRUCTION PROJECTS

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Critical path method (CPM) is commonly used in scheduling of construction projects. However, CPM only considers the precedence relations between the activities and does not consider resource optimization during scheduling of projects. Optimal allocation of resources can be achieved by resource levelling. Resource levelling is crucial for effective use of construction resources particularly to minimize the project costs. However, commercial scheduling software has very limited capabilities for solving the resource levelling problem. In this study a genetic algorithm (GA) is developed for the resource levelling problem. The performance of GA is compared with the performance of Microsoft Project 2010 for several sample projects. The comparisons indicate that the GA outperforms resource levelling heuristic of Microsoft Project 2010 significantly. Furthermore, exact solutions were obtained for the sample problems using linear-integer programming technique. Exact solutions reveal that the algorithm is capable of achieving adequate solutions. Hence, the GA provides a powerful alternative for the resource levelling problem.

Keywords: project management, resource levelling, genetic algorithms, optimization

INTRODUCTION

Critical path method (CPM) is commonly used for scheduling of construction projects. However, CPM is not capable of minimizing undesirable fluctuations in resource utilization profile (Hegazy 1999; El-Rayes and Jun 2009). Inefficient planning of resource utilization profile may result in idle workforce, or may present the need to hire and release the workers in short periods which can make attracting and keeping qualified workforce difficult (El-Rayes and Jun 2009; Harris 1978). Therefore, resource levelling problem (RLP) is crucial in project scheduling for achieving optimal allocation of resources.

There are several exact and heuristic methods in literature which have been proposed for solving the RLP. Exact methods based on linear-integer programming technique have been proposed initially by Easa (1989). Exact methods such as linear-integer programming can be implemented to solve small problems but, exact methods have

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several limitations due to complexity of the RLP. Hence, numerous researches have focused on heuristic methods. Initial heuristic methods implemented the priority-based procedures for the RLP (Burgess and Killebrew 1962; Harris 1990; Martinez and Ioannou 1993). The developments in meta-heuristic algorithms in recent years enabled powerful alternatives for the RLP. Genetic algorithms (GAs) (El-Rayes and Jun 2009; Hegazy 1999; Leu *et al.* 2000; Zheng *et al.* 2003), simulated annealing (Son and Skibniewski 1999), ant colony algorithms (Xiong and Kuang 2006; Geng *et al.* 2010) and particle swarm algorithms (Qi *et al.* 2007; Pang *et al.* 2008; Guo *et al.* 2009) are among the meta-heuristics implemented for the RLP. Majority of the existing research have focused on solving very small networks and did not evaluate the performance of commercial software (such as; Microsoft Project, Primavera etc.) for the RLP. The main objective of this paper is to develop an efficient GA for RLP. The GA will be used to minimize the absolute deviation between the resource requirement and the average resource consumption.

PROBLEM FORMULATION

The purpose of general RLP is to minimize the undesired fluctuations in the resource utilization profile with respect to an objective function while satisfying the precedence relations and without changing the CPM project duration. In other words, the objective of RLP is to schedule the non-critical activities in such a way that the fluctuations in the resource utilization profile are minimized, precedence relations are satisfied, and the project duration is not changed.

Numerous resource levelling metrics have been proposed to measure the fluctuations in the resource utilization profile. Sum of squares of daily resource requirements, and the absolute deviation between the resource requirement and the average resource consumption (AbsDev) are the two metrics that are commonly used for solving RLP. The AbsDev metric is considered in this research, because, it is used by of Microsoft Project' s heuristic to solve RLP and it can also be formulated easily by linear-integer programming. The objective of AbsDev is to minimize the deviation between the resource requirements and a desirable constant resource rate. The mathematical formulation of the objective function for the AbsDev is as follows:

(1)

$$AbsDev = \sum_{m=1}^{n} \left| U - R_m \right|$$

and,

(2)

$$U = \frac{\sum_{x=1}^{y} DM_x \times DU_x}{n}$$

Where, “n” is the project duration and “Rm” is the requirement of all activities at the day m. In addition to these, “U” represents uniform resource level, “y” is the number of activities, “DMx” is the total demand of activity x and DUx is the duration of activity x. In this paper the average resource consumption is used to determine the uniform resource level U, as shown in Eq. (2).

GENETIC ALGORITHMS

Genetic search algorithms are population based search strategies inspired by the principles of natural selection. In GAs, first a population of chromosomes is generated for natural selection. Each chromosome represents a set of numerical data, a possible solution to the optimization problem. These chromosomes are composed of genes. By manipulating the genes, new chromosomes are created. These manipulations occur through by mating the two parent chromosomes using a crossover operation (Figure 1), or by altering a gene slightly using a mutation operator (Figure 2). During each generation a fitness function is used to determine the performance of the chromosomes. The driving force in GAs is the selection of chromosomes based on the fitness function (Blum and Roli 2008). The fitter chromosome is assigned a higher chance of survival hence; in general the fittest individuals are passed to the next generations. Eventually after several generations, the population is expected to converge to the optimal solution.

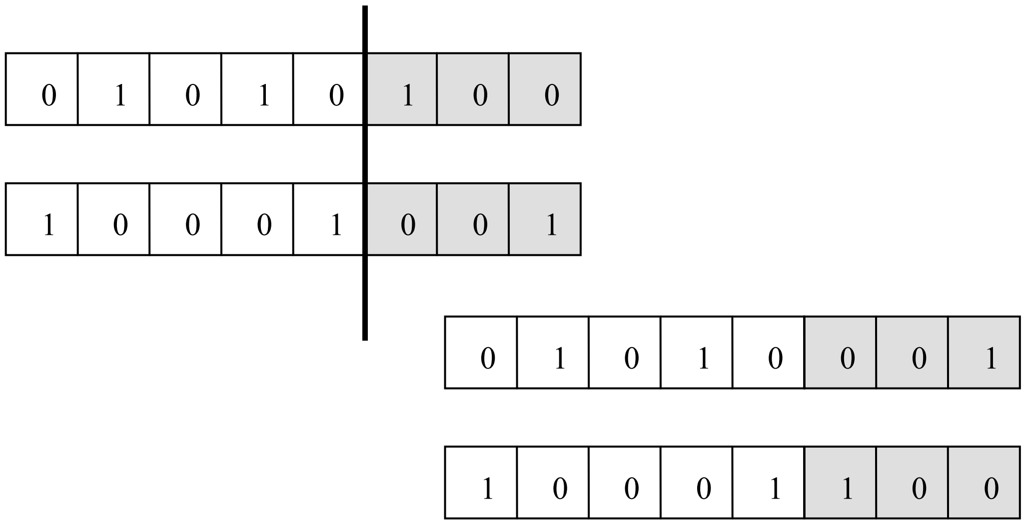

Figure 1. Crossover Operator

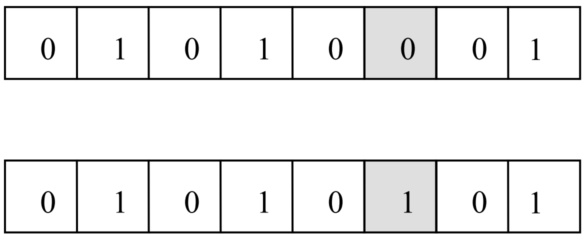

Figure 2. Mutation operator

GAs in recent years have been a very popular tool for solving optimization problems that are similar to RLP. Although a GA does not always guarantee to find the optimal solution, it is a powerful technique to search and find optimal or near optimal solutions in a reasonable period of time. The computational procedure of GA developed in this study includes the following 3 steps:

1) CPM scheduling

The CPM method is used in this step to define the critical path, to calculate the project duration and to determine the activity start and finish dates, and floats. The procedure for this step is performed as follows:

- The data required for scheduling including each activity's ID number, duration, successors and daily resource demand are inputted.

- The early start time (ES) and early finish time (EF) are determined using forward-pass, then, the late finish time (LF) and late start time (LS) and the total float (TF) for each activity are calculated using backward-pass.

2) Generation of Initial population

At this step a pre-determined number of chromosomes (Nc), is generated as the initial solution population according to the following procedure:

- Nc numbers of chromosomes are generated randomly. Each chromosome is formed of genes that represent a start time selection for the non-critical activities.
- The objective function values of the initial population are determined using equations (1) and (2).

3) Implementation of genetic operators

In order to create the next generation populations, genetic operators such as crossover and mutation are implemented at this stage as follows:

- According to a predefined crossover probability (Pc), some chromosomes from the previous solution generation are selected randomly. Then they are used to generate the new chromosomes by implementing the one-point uniform crossover operator.
- The chromosomes that will be selected for the next generation are determined by the elitist roulette-wheel selection. In this technique the chromosome with the best objective function value is first selected for the next generation. The remaining chromosomes are selected based on a probability determined according to the value of their objective function. In this selection method the chromosomes with a better objective function value have better chance to survive.
- The mutation operator is implemented next according to the predetermined mutation probability (Pm). A number of chromosomes are selected at this step according to the Pm rate and the mutation operator is performed to obtain the new chromosomes.

Steps 2 and 3 are repeated until a predefined number of solutions (Ns) are reached. In the final stage, the last generation's best solution is considered as the solution of the problem.

TEST PROBLEMS

16 problem instances related to RLP were selected from the literature to test and compare performances of the GA and Microsoft Project 2010. All of the problems included a single resource. The sources and number of activities of the test problems are shown in Table 1. The activity numbers in the table does not include the start and finish dummy activities.

Table 1: Sources of the selected problems

No	Number of activities	Source
1	20	El-Rayes and Jun (2009)
2	15	Stevens (1990)
3	19	Stevens (1990)
4	11	Harris (1990)
5	13	Leu *et al.* (2000)
6	13	Son and Skibniewski (1999)
7	11	Son and Skibniewski (1999)
8	7	Mutlu (Generated II) (2010)
9	13	Mutlu (Generated V) (2010)
10	14	Mutlu (Generated VI) (2010)
11	14	Mubarak (2004)
12	11	Mubarak (2004)
13	8	Mubarak (2004)
14	15	Hinze (2004)
15	10	Demeulemeester and Herroelen (2002)
16	5	Easa (1989)

COMPUTATIONAL RESULTS AND COMPARISONS

The proposed GA was developed on a 64 bit platform using C# programming language. All of the instances were tested in a personal computer with a processor speed of 2.67 GHz. The GA was able achieve solution for each of the problem instances within a processing time of 5 seconds.

The optimal solutions for the problem instances were obtained by using the linear-integer programming technique (Easa 1989). The percent deviations from the optimal solution for Microsoft Project 2010 and GA are shown in Table 2. The proposed GA was able to determine the optimal solution for 8 of the 16 instances (50 %), and it had an average percent deviation value (from the optimal solution) of 4%. Whereas, Microsoft Project was able to determine the optimal solution for only two of 16 instances (12.5 %), and it had average percent deviation value of 44 %. The results demonstrate that the proposed GA was able to achieve reasonably adequate results and outperforms the levelling heuristic of Microsoft Project significantly. Hence the results of Microsoft Project are far away from the optimal even for very small networks including only 10 activities.

Table 2: Percent deviations from the optimal solution

No	MICROSOFT PROJECT 2010	GA
1	31%	2%
2	66%	6%
3	51%	5%
4	88%	0%
5	75%	6%
6	86%	19%
7	74%	0%
8	0%	0%
9	37%	0%
10	40%	0%
11	8%	3%
12	7%	3%
13	4%	0%
14	64%	0%
15	80%	20%
16	0%	0%
Average Dev.	44%	4%

CONCLUSIONS

A GA was developed to minimize the undesired fluctuations in the resource utilization profile of construction projects. Comparisons of the proposed GA with Microsoft Project indicated that the GA outperforms Microsoft Project's heuristic significantly for the RLP. In order to evaluate the GA's performance, exact solutions were obtained for the sample problems using linear-integer programming technique. Exact solutions revealed that the algorithm is capable of achieving adequate solutions. The results demonstrated the limitations of Microsoft Project and the need for better heuristics to solve RLPs in construction projects. The results also revealed that the GA is a good alternative for solving the RLPs. Hence, GA provides a powerful alternative for minimizing the undesirable fluctuations in resource utilization profile to achieve efficient and optimal construction project schedules.

Although the proposed GA yielded reasonably adequate results, it may require some improvements to solve large networks with multiple resources. Hybrid using of GA with other meta-heuristic algorithms may provide a potential for further improvement to achieve an algorithm that can efficiently solve the RLPs for large size construction projects.

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