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Resource Leveling of an Industrial Building Using Genetic Algorithm Technique

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ABSTRACT

Construction companies should schedule their projects in a manner that considers the efficient use of limited resources in order to complete a project within estimated budget, on schedule and in compliance with the specifications. In this context, the planning of resources becomes crucial for a construction project, which can be accomplished by resource leveling. Resource leveling —also known as resource smoothing— is a method that attempts to reduce the fluctuations in resource usage in order to make the resource requirements as uniform as possible while maintaining the original project duration. The studies dealing with resource leveling problems can be classified into two categories, which are; (1) analytical methods and (2) heuristic methods. Analytical methods may give optimal solutions on small-scaled problems; however, they are inadequate in large-scaled problems. As a result of the weaknesses of analytical methods, many studies have been conducted in order to develop more efficient models by heuristic methods. Genetic algorithm-based resource leveling is one of these models, which is developed to attain better solutions. The main objective of this study is to handle the resource leveling problem of an industrial building using genetic algorithms. In this context, a schedule for an industrial building is established using the Critical Path Method (CPM). The information about the logical constraints and the resources required to carry out activities were obtained through the interviews with civil engineers from the company, whose expertise is on industrial buildings. The proposed genetic algorithm based resource leveling model attempts to improve the schedule. The developed model provided a decrease of 20% in the total resource-days required to complete the project. The study is of benefit to participants of construction industry, because it makes them aware of the potential use of the combination of critical path method and genetic algorithms in order to solve the resource leveling problem.

INTRODUCTION

There are a number of scheduling techniques, such as Gantt Charts, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), etc., used in construction projects. The Critical Path Method (CPM) has been the most preferred one by construction practitioners for scheduling since the 1950s [1-6]. Nevertheless, it has a major limitation as it assumes that resources, such as workers, machines etc., are unlimited [5, 7]. Thus, several studies focusing on optimal use of resources on CPM networks were conducted. Generally, there are two approaches commonly used for resource utilization. The first approach considers that there are limited resources, which is named as resource allocation (also known as resource-constrained scheduling). The main objective of this approach is to keep the extensions of construction project duration as little as possible, in a manner which considers constraints on resources [7]. The second approach, which is called resource leveling (also known as resource smoothing), assumes that there are sufficient resources available, however, the project duration is limited and cannot be increased. The goal of resource leveling is to minimize fluctuations, peaks and valleys in resource requirements without changing the completion time of a project [2, 5, 7 - 13]. The resource leveling technique for an original form of CPM networks generally consists of two main stages. The process begins with a forward and backward pass analysis in order to determine early and late start and finish dates considering interdependencies in addition to logical and technological constraints among activities. The second step consists of basic CPM scheduling calculations which determine critical activities and float times of non-critical activities. Following that, start times of non-critical activities are shifted along their available float times in order to level resources, in other words smooth the resource histograms [4].

The main objective of this study is to investigate the impacts of two different objective functions on resource histograms. For this purpose, an attempt is made in order to develop a genetic-algorithm based resource leveling model for schedules established through CPM. A case study is presented to illustrate the obtained solutions for two different objective functions, which are used in resource leveling of CPM networks. Finally, the last section consists of conclusions derived from this study.

RESOURCE LEVELING

Resource leveling (also known as resource smoothing) is a method which attempts to reduce the fluctuations in resource requirements without changing the original completion time of the construction project. In other words, the main goal of resource leveling is to obtain a desired flow of resource demand histogram without changing the project duration. In essence, non-critical activities may shift along their available float times, which are determined through basic CPM calculations, in order to level the resources [2, 9, 12, 13].

The methods used in studies dealing with resource leveling problems in the literature, can be classified into two categories: (1) analytical methods and (2) heuristic methods [2, 8, 13]. Even though analytical methods may provide optimal solutions on small-scaled problems, they are inadequate for large-scaled problems. Heuristic methods may not give the best solution in all construction cases due to their problem-dependent nature; however, they may perform well in practice due to their simple format [2, 13]. Genetic algorithm-based resource leveling is one of those heuristic methods, which is developed in order to attain better solutions. Al-Tabtabai and Alex (1999) [14], Hegazy (1999) [9], Leu et al. (2000) [2], Ogwu and Tah (2002) [15] conducted studies which provide detailed information regarding genetic algorithm based resource leveling. These studies revealed that inefficient resource utilization in construction projects may adversely affect the project duration and cost. As a matter of fact, resource utilization should never be ignored to prevent unrealistic schedules [5, 9, 12].

GENETIC ALGORITHMS

Genetic algorithms can be defined as search methods that locate the global optimum solution by simulating the natural selection process in which stronger individuals survive in a competing environment. The study of John Holland represents a starting point for the use of genetic algorithms in areas such as constrained or unconstrained optimization, scheduling and sequencing, resource allocation and leveling, etc. [2, 9, 13]. Genetic algorithms search the potential solution of a problem in a population of chromosomes (also known as string). Each chromosome in a population represents a potential solution. Also, each chromosome consists of a series of genes, which represent a value of a variable for a particular problem. These values might be represented as either binary or real numbers [9].

The chromosomes evolve through reproduction process among the population members. This process, which produces an offspring that might take part in the population as an alternative solution for the problem, might be conducted by crossover and mutation. In crossover (a.k.a. marriage) operation, a particular parent chromosome fragmented into parts through a pre-determined crossover rate in order to merge its parts with corresponding parts of another parent chromosome. In mutation operation, contrary to crossover, an offspring might be produced by arbitrarily changing genes of a parent chromosome which is selected randomly from the population [9, 13]. An offspring is evaluated through an objective function (a.k.a. fitness function) and the constraints. As a consequence of this evaluation, only the chromosomes, which fit more to the objective function than others in the population, might survive in order to produce new offspring. This process (Figure 1) usually continues until a chromosome, that represents the optimum solution for a particular problem, is produced [2, 9].

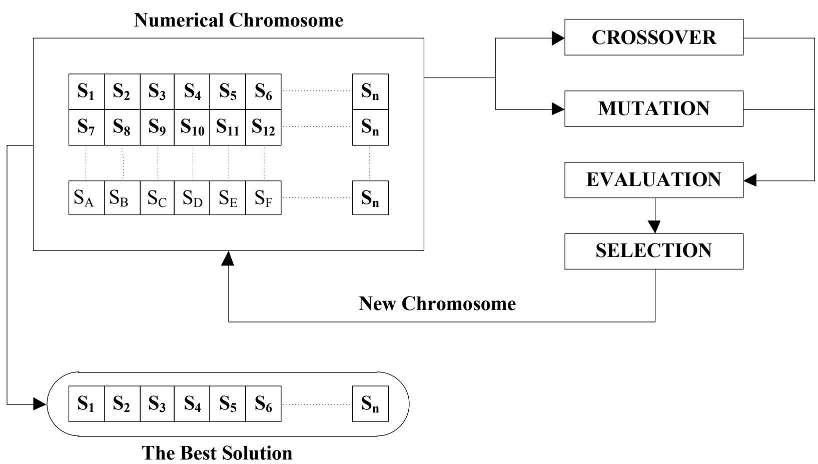

Figure 1 Example for an operational flow of a genetic algorithm [2]

GENETIC ALGORITHM-BASED RESOURCE LEVELING

The main objective of this study is to develop a genetic algorithm-based resource leveling model for construction projects, which are scheduled using the CPM. In this context, a schedule for a real-life steel framed industrial building is established using the CPM. The information about the activity durations, interdependencies, logical constraints and the resources required to carry out the activities were obtained through the interviews with civil engineers from the company, whose expertise is on industrial buildings. The activity durations and required resource amounts are the optimum values that are determined according to the experience gained from previous similar projects, which were completed by the construction company in question. The industrial building is 48 m in width, 208 m in length, 8 m in height, and 16 m in column span. The activity network of the construction project is established by MS Project without considering limitations on resources. The network mainly consists of 6 activities, which are repetitive throughout the construction project: (1) fabrication of primary and secondary columns, (2) fabrication of trusses, (3) fabrication of purlins, (4) column erection, (5) truss assembly, (6) purlin assembly. However, there are 2,530 repetitive activities, which begin with site mobilization stage and end with completion of the steel framed industrial building. MS Project is used as scheduling software in order to determine the total project duration—44 days—through basic CPM calculations. Also, the total float values of activities are calculated through basic CPM calculations by MS Project. Despite the fact that a number of different resource types are necessary for completing the activities of the steel framed industrial building, this study considers only workers. The logic diagram is also shown in Figure 2 rather than all CPM network due to the difficulty in presenting a network consisting of such a large number of activities.

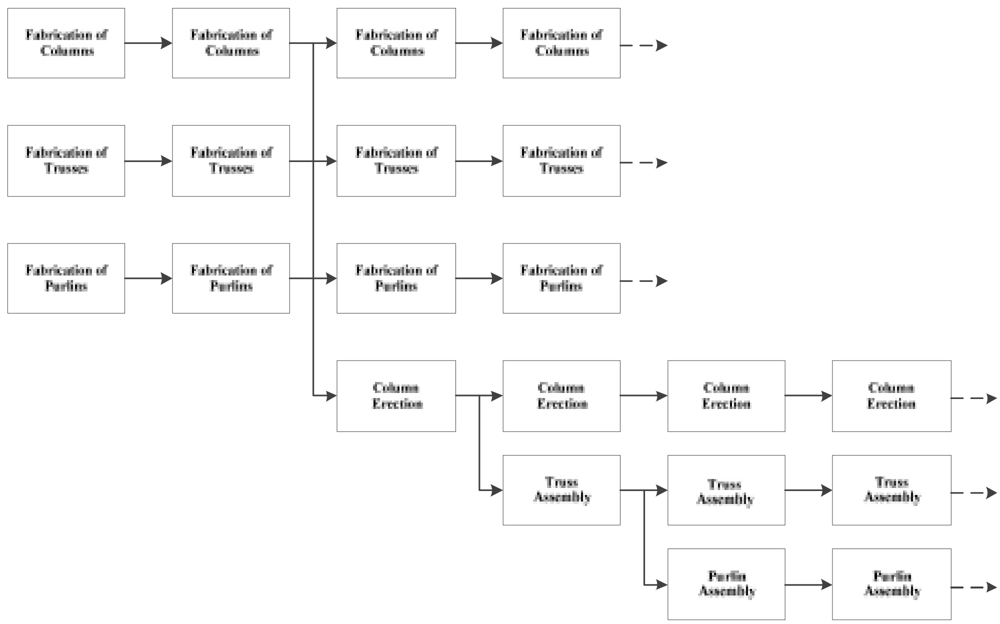

Figure 2 Logic Diagram for the CPM Network

The initial resource histogram for the initial CPM network is drawn before developing the genetic algorithm based resource leveling model. The desirable daily resource requirement (d_{rr}) is calculated by dividing the total duration of the project into the number of resource-days obtained from the initial histogram: 7,753 resource-days/44 days = 176.20 resource-days/days. This result is rounded up to 177 resource-days/days due to the nature of the resource type (i.e., worker) that is used in this study. Also the sum of absolute value of the deviations between the resource requirements on any day and the desirable resource requirement is calculated as 3,561 for the initial resource histogram (Figure 3). In the foregoing paragraphs, the details of the development of the genetic algorithm model in order to minimize this value through resource leveling are given.

The genetic algorithm based resource leveling model is developed with an add-in program for Microsoft-Excel called Evolver 5.5 [16]. Evolver 5.5 has been selected in order to develop the model as it has superior features such as fast model setup, handy playback controls, process speed etc. Hegazy and Ersahin (2001) [11] also used an earlier version of Evolver (Evolver 4.4) in their study. The development process through Evolver 5.5 contains four steps: (1) defining the Microsoft-Excel cells that represent the variables, (2) defining the Microsoft-Excel cell that represents the objective function, (3) specifying constraints, and (4) identifying the selection strategy.

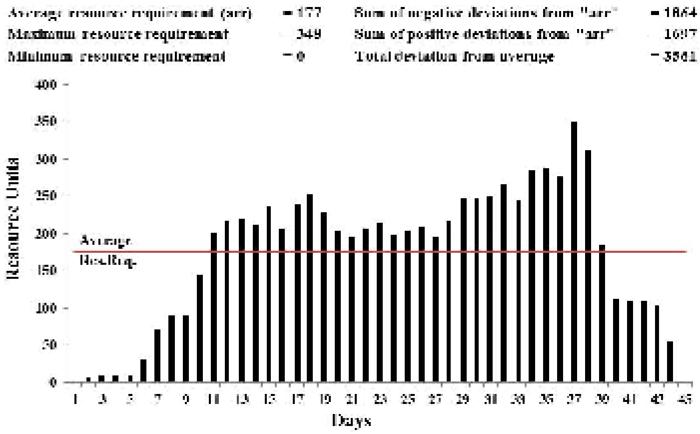

Figure 3 Resource Histogram before Resource Leveling

The first step is a chromosome representation (the solution representation) which corresponds to defining the Microsoft-Excel cells that represent the variables. A solution for the resource leveling problem is represented by a chromosome which consists of genes [17]. In this study, the value of a gene corresponds to a possible starting date of a particular activity. The total number of genes is equal to the total number of activities which are required for the completion of the project. The variables of this study are the start times of the activities which range between the early start times and late start times. In other words, the start times of the activities are shifted according to the total float values of the activities.

The second step is the determination of the objective (fitness) function, which evaluates each generated chromosome. Evolver 5.5 provides three different optimization goals, which are named as minimum, maximum and target value. Also the user selects a Microsoft-Excel cell in order to define the objective function. In this study, there are two different objective functions that are used for the solution of the resource leveling problem without changing the total project time. The first one is minimization of the sum of the absolute deviations between daily resource requirements and the desirable average resource requirement, which is one of the most preferred objective functions for resource leveling. The second one is minimization of the maximum daily resource requirement, which might be one of the most desired situations for contractors. The formulations of the objective functions are as follows:

(1) Minimization of the sum of the absolute deviations between daily resource requirements and the desirable average resource requirement,

$$Z = \min \sum_{i}^{T} \left| R_i - R_{avr} \right| \qquad (1)$$

where *min* refers to minimize; *i* refers to day under consideration; *T* refers to the duration of the project; R_i refers to resources required on day *i*; R_{avr} refers to desirable average resource requirement.

(2) Minimization of the maximum daily resource requirement,

$$Z = \min\left[\max(R_i)\right] \qquad (2)$$

where *min* refers to minimize; *max* refers to maximum; *i* refers to day under consideration; R_i refers to resources required on day *i*.

After the determination of the objective (fitness) function, constraints have been specified for the model via the user friendly command window of Evolver 5.5. The constraints consist of the minimum and maximum start date values that can be used for activities of the project. These values are determined according to the total float values, which are calculated according to basic CPM calculations. The next step is the identification of selection strategy. There are six solving methods corresponding to selection strategies provided by Evolver 5.5. These solving methods are selected according to the characteristics of the problem. In this study, the "recipe" method is selected due to the independent adjustment of each variable from the others. Hegazy and Ersahin (2001) [11] also used the same solving method in their study. After the objective function, constraints and selection strategy are set, the population size, crossover and mutation rates should be determined. The population size is determined as 50—which is the default value of Evolver 5.5—for this study. The crossover and mutation rates are set as 0.5 and 0.1 respectively, which are the default values of Evolver 5.5 and can be changed according to the nature of the problem. Once all the inputs are set, the process for the genetic algorithm model is run by Evolver 5.5. The process is carried out for two aforementioned different objective functions. Each of the processes is stopped after 100,000 trials due to the inability to come up with any better solution. Also, the resource histograms, which are important to see the variability of resource requirements, are generated by Microsoft-Excel.

The first objective function attempts to minimize the sum of the absolute deviations between daily resource requirements and the desirable average resource requirement, which is one of the most commonly used objective functions in the literature. The proposed genetic algorithm based model considering the aforementioned objective function, improves the original resource histogram by reducing the maximum daily resource requirement from 348 resources to 306 resources, which corresponds to a 12% improvement. Moreover, the percentage of improvement in minimizing the sum of absolute deviations between daily resource requirements and desirable average resource requirement (2,479) is 30%. The new resource histogram after resource leveling is shown in Figure 4.

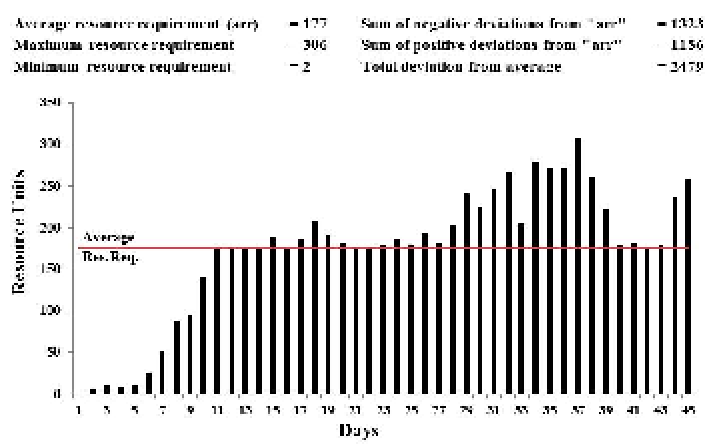

Figure 4 Resource Histogram after Resource Leveling for Objective Function of Minimize the Sum of the Absolute Deviations between Daily Resource Requirements and the Desirable Average Resource Requirement

The second objective is to minimize the maximum daily resource requirement, and it is observed that after genetic algorithm based resource leveling, the maximum daily resource requirement obtained from the new resource histogram is reduced to 256 resources from 348 resources, which corresponds to an improvement of 26%. In addition, the sum of absolute deviations between daily resource requirements and desirable average resource requirement is calculated as 3,093 with an improvement of 13%. Figure 5 shows the new resource histogram after the resource leveling.

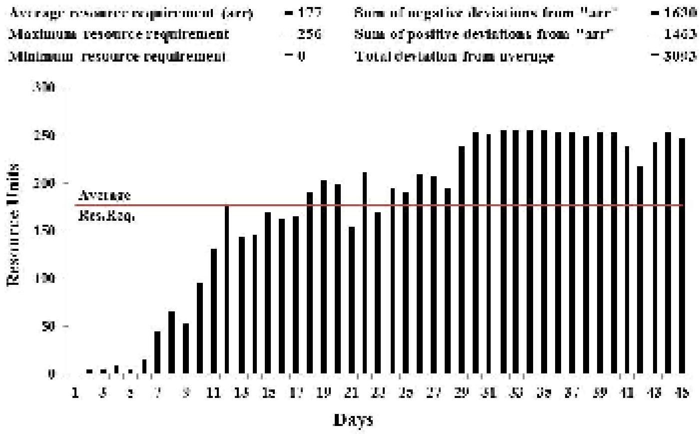

Figure 5 Resource Histogram after Resource Leveling for Objective Function of Minimize the Maximum Daily Resource Requirement

CONCLUSIONS

Construction companies should schedule their projects in a manner that considers the efficient use of limited resources in order to complete a project within estimated budget, on schedule, and in compliance with the specifications. Resource leveling is one of the most preferred approaches in efficient utilization of limited resources. In this paper, an attempt is made in order to develop a genetic-algorithm based resource leveling model, which is used on a real-life construction project as a case study. Also, this study presented the resource histograms, which were obtained after the genetic algorithm based resource leveling process that considered two different objective functions. The first objective function is minimizing the sum of the absolute deviations between daily resource requirements and the desirable average resource requirement, which is one of the most common used objective functions in the literature. The second objective is to minimize the maximum daily resource requirement, which might be one of the most desired situations for contractors. The resource histograms, which were obtained after the genetic algorithm based resource leveling, indicated that using different objective functions might give different results. In this context, the study is of benefit to the participants of construction industry, because it makes them aware of the fact that resource leveling may not be successful without using the adequate objective function, which should consider the characteristics of projects, needs of contractors, etc.

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