Multi-Population Symbiotic Organisms Search Algorithm for Solving the Construction Resource Leveling Problem

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Abstract. During any type of construction project, a necessary factor that determines success is proper scheduling. Different implementation methods seem to have been undertaken for scheduling, like program evaluation review technique (PERT), critical path method (CPM), as well as Gantt charts. These methods assume that there are unlimited resources available, which may fluctuate the demand of resources and may result to increased cost. A method used to efficiently allocate resources such that resource demand fluctuation is reduced is called resource leveling. Some studies have employed some metaheuristic methods as an alternative to resource leveling, such as genetic algorithm (GA) and particle swarm optimization (PSO). However, each method has their own shortcomings; one of these shortcomings is overreliance on parameter tuning. If there is no optimization of the parameter setting, additional computational time is needed to find the best solution to the problem. Recently, there has been an increase in the use of the symbiotic organisms search (SOS) when addressing many optimization issues in different research fields. SOS does not need a particular parameter tuning given that it uses only common parameters like iteration numbers and population size to operate unlike the majority of other population-based metaheuristic algorithms. Thus, this study investigates the performance of SOS in solving the construction resource leveling problem. A construction project with 44 activities is adopted as the main case study. In this research, the SOS has been modified to accommodate the multi-population feature in order to increase the its searching ability. To study the comprehensive effect of resource fluctuation, instead of only using one resource fluctuation criterion, this study integrates two different objective functions with different resource utilization diagrams. It can be seen throughout the simulation process that MP-SOS is able to reduce the resource fluctuation significantly in both objective functions.

INTRODUCTION

To succeed in any construction project, it is important to create a proper schedule. Scheduling can be done in various ways, such as the critical path method (CPM), Gantt charts, and program evaluation and review technique (PERT) [1]. Since 1950, the schedules of big construction projects are planned and controlled by the most popular scheduling methods like CPM and PERT [2]. There are so many drawbacks to CPM, even though it is the most commonly used method of scheduling. This method assumes that there are unlimited resources available, which may fluctuate the demand of resources. It is infeasible and costly to employ and sack construction workers within a very short time in order to meet the unstable resource requirements [3]. As a result, this condition may result to increased cost. Thus, resources should be efficiently allocated and managed to avoid increased costs and delay in the execution of the project.

A method used to efficiently allocate resources such that resource demand fluctuation is reduced is called resource leveling. This can be done by handling insignificant activities at other times such that the duration of the project is not affected [1]. Burgess and Killebrew [4] developed one of the earliest methods of resource leveling, in which the overall sum of the squares of the resource usage was reduced so as to realize a smooth rectangle-shaped resource histogram. Wagner et al. [5] suggested various objective criteria for resource leveling, such as reduction of the total sum of absolute deviations with respect to resource usage for a specific time interval, and reduction of the maximum usage of resources for a certain time period. At a later time, Leu et al. [2], Easa Said [7], and Hossein Hashemi Doulabi et al. [6] suggested a new criterion for resource leveling, which is the reduction of the total sum of the absolute deviations between the usage of resource for a specific time period.

At the beginning, to solve resource leveling problems, mathematical approaches were employed. Nevertheless, these approaches can no longer be applied to big construction projects. After a while, heuristics methods were employed [8, 9], but these methods still cannot produce the best results [10]. Due to these drawbacks presented by both the heuristic and mathematical methods, a lot of researchers started studying metaheuristic approaches so as to find better optimization alternatives in order to solve problems associated with resource leveling.

Some studies have employed some metaheuristic methods as an alternative to resource leveling, such as ant colony organization (ACO) [11], genetic algorithm (GA) [2, 6], particle swarm optimization (PSO) [12], and differential evolution (DE) [10]. Nonetheless, each of these methods have their own shortcomings; one of these shortcomings is overreliance on parameter tuning. If there is no optimization of the parameter setting, additional computational time is needed to find the best solution to the problem. In addition, there might be a convergence of the solutions provided by these metaheuristic algorithms to a local optima region.

Over the last few years, there has been an increase in the use of the symbiotic organisms search (SOS) when addressing many optimization issues in different research fields [13-15]. The searching operators of SOS are inspired by the phenomenon of interaction of organisms in nature. SOS doesn't need a particular parameter tuning given that it uses only common parameters like iteration numbers and population size and to operate unlike the majority of other population-based metaheuristic algorithms. In regard to SOS, there are optimization routines that are nature-inspired and are used to iteratively get optimal solutions, which are the commensalism phase, the parasitism phase, and the mutualism phase. It has been noted that SOS surpasses the performance of DE, PSO, and GA in some problems [13], its performance when it comes to solving resource leveling problems, for example, has to be tested further.

Due to its complex nature, resource leveling has now become a major subject whenever construction is considered [16]. Researchers have implemented heuristic and mathematical methods for handling resource leveling [7-9], yet it is not practical when proffering solutions to the advanced problems to encounter on ideal cases. Later, metaheuristic approaches have been employed for solving resource leveling, but there is still room for improvement so it can yield much better solution as well as solve more advanced problems. This research examines the use of SOS and Multi-Population concept in offering solutions to resource leveling problems.

MULTI-POPULATION SYMBIOTIC ORGANISMS SEARCH

Symbiotic Organisms Search

Cheng and Prayogo formulated SOS in 2014, as a promising and new metaheuristic algorithm [13]. This particular algorithm is inspired by symbiosis communications of living things in nature. A description of the three used phases in SOS, which are mutualism phase, commensalism phase, and parasitism phase, is as contained below:

- Mutualism Phase: Mutualism is the interaction ongoing between 2 organisms that are different provides the benefit for the two of them. The relationship existing between the flower and its pollinator is pure mutualism. The flower provides the pollinator with its foods, and the pollinator aids in the flower in becoming fruit through pollination. Thus, the two organisms benefit from one another and the process is called 'Phase of benefits.'
- Commensalism Phase: Commensalism is whenever the two organisms interact it is only one of them that actually benefits while the other neither suffers nor benefits as a result of the relationship. The shark and remora fish relationship are one of commensalism. The remora fish attaches itself to the back of the Shark while consuming leftover foods from there. The shark is not in any way affected by what the remora fish does, hence, it never gets any benefit from the relationship.
- Parasitism Phase: On this occasion, the interaction existing between the two organisms end up eliminating the organism that is weaker from that ecosystem. The dictionary does not define parasitism as the act of eliminating an individual by another, hence a more appropriate word could be predation. Nevertheless, as

Cheng and Prayogo [13], SOS inventor has implied the term parasitism to mean an organism eliminating another, it has been kept that way in the course of this study.

Multi-Population Optimization

In this research, multi-population concept has been added to the SOS algorithm. This multi-population concept has been studied and being used by multiple optimization algorithms, including GA and PSO. First, the population of organisms will be divided into several sub-population. Each sub-population will go through three phases: mutualism phase, commensalism phase, and parasitism phase. Every a number of iterations, small amount of organisms in each sub-population will be swapped to introduce a possibility of searching direction. The multi-population concept can be further expanded in the future with parallel computing technique to speed up the computational time. The Multi-Population SOS (MP-SOS) is shown in Figure 1.

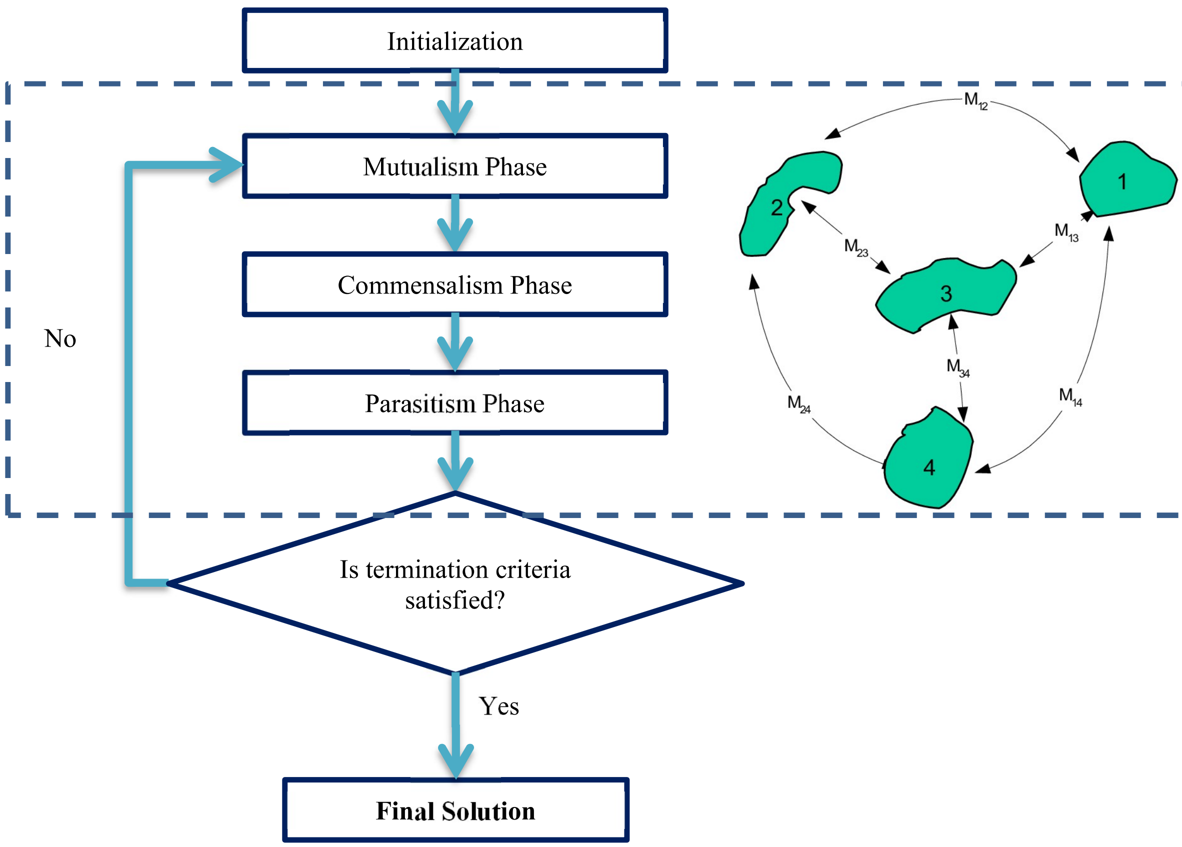

FIGURE 1. The flowchart of MP-SOS

PROJECT INFORMATION AND EXPERIMENTAL SETTINGS

This paper investigates MP-SOS performance as it concerns finding solution to resource leveling challenge with 2 resource leveling objective criteria that have been employed in past literatures. For instance, a case study of a construction project having 44 activities was taken from Prayogo et al. [10] particularly for this study. The network diagram of the proposed case study is shown in Figure 2.

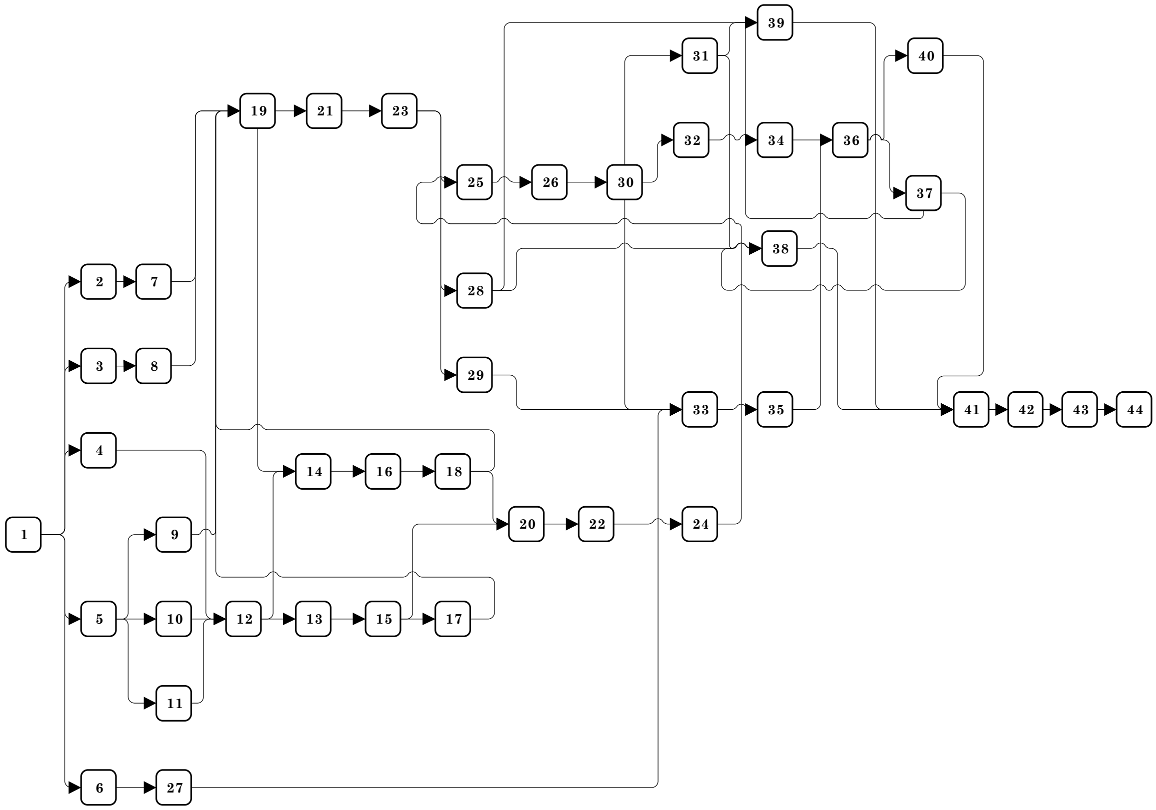

FIGURE 2. Network diagram of the construction project.

Every algorithm is put through simulation up to 30 times along with 100 iterations and 300 populations. The project details can be seen from Prayogo et al. [10]. Two objective functions were adopted from Ref. [5] and [7] as shown in Equations 1 and 2. The diagram of the resource demands prior to leveling can be seen in Figure 1.

$$Z = \min \sum_{i=1}^{T} (|Rdev_i|) \tag{1}$$

$$Z = \min \sum_{i=1}^{T} (|Rinc_i|) \tag{2}$$

where T is the project duration, i is the determined time interval (day, week, etc), $Rdev_i$ is deviation of the resource demand on i and $i+1$, $Rinc_i$ is the increase of resource demand on i and $i+1$.

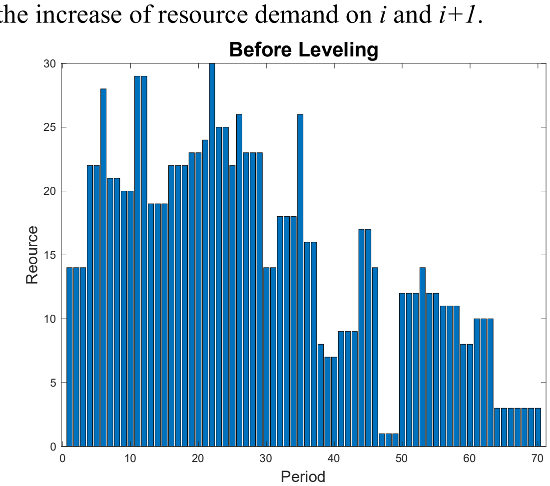

FIGURE 3. Before leveling resources diagram.

OPTIMIZATION RESULTS

This section features SOS performance regarding how it solved the problem of resource leveling and how the objective functions were compared against it. The optimization output is gotten via 30 simulations for evaluating the accuracy and consistency in Table 1 and 2. The most reliable objective value established within the final iteration of all the runs would be gathered. Moreover, the standard, average, worst, and best deviation values were duly computed according to the 30 objective values gotten from the simulation runs. Figures 4 and 5 depicts the improvements of after leveling using SOS. For each objective function, the value before leveling are 164 and 75, respectively. It is noted that SOS can improve each objective value up to 67.07% and 73.33%, respectively.

TABLE 1. Optimization results for the first objective function

Objective Function	MP-SOS
Best	54.00
Mean	66.55
Std	5.51

TABLE 2. Optimization results for the second objective function

Objective Function	MP-SOS
Best	20.00
Mean	29.00
Std	2.15

Table 1 and Table 2 indicate that the MP-SOS manage to achieve a result with a good consistency. The standard deviation for each objective function are considered low. After the optimization and leveling have been conducted, the resource diagrams are shown in Figure 4 and 5. Observing Figure 4 and 5 gives indication that the fluctuation of the resources diagram has been successfully reduced.

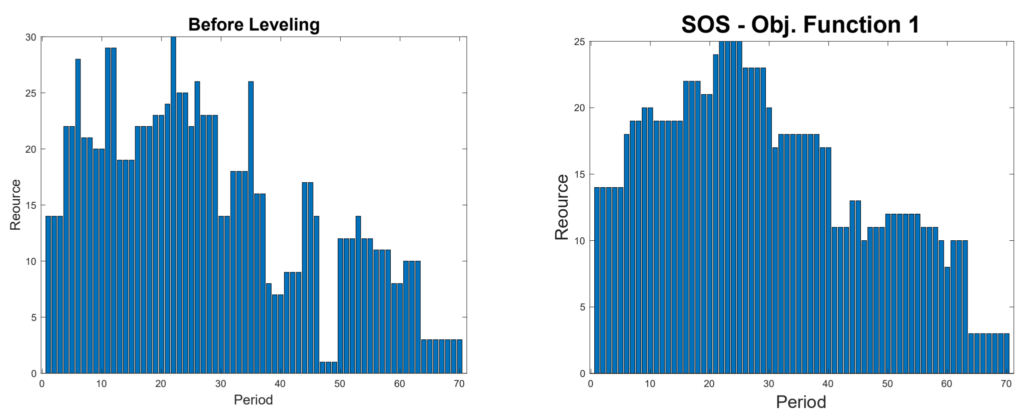

FIGURE 4. Before and after leveling resources diagram for first objective function.

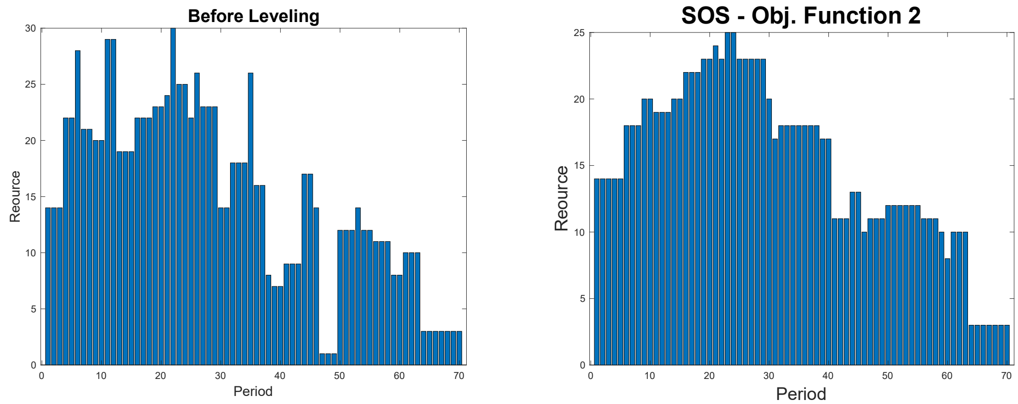

FIGURE 5. Before and after leveling resources diagram for second objective function.

CONCLUSION

The research objective is to examine SOS performance regarding solving resource leveling challenges using a CPM networked resource diagram. The optimization of the two objective functions was conducted with SOS as the optimization algorithm. In this research, multi-population concept has been added to the SOS algorithm to enhance the performance of SOS, so-called Multi-Population SOS (MP-SOS). Those two objective functions produce different resource demand diagrams because they individually minimize different variables. MP-SOS algorithm is more efficient when it comes to solving e challenges of resource leveling. It can be seen throughout the simulation process that MP-SOS is able to reduce the resource fluctuation significantly in both objective functions.

ACKNOWLEDGMENTS

Authors wishing to acknowledge the present research is financially supported by The Ministry of Research, Technology and Higher Education of the Republic of Indonesia under the Penelitian Dasar Unggulan Perguruan Tinggi (PDUPT) 2021 Research Grant Scheme.

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