Automation in Construction 77 (2017) 82–92

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Improved Adaptive Harmony Search algorithm for the Resource Leveling Problem with minimal lags

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ARTICLE INFO

Article history:
Received 28 June 2016
Received in revised form 17 January 2017
Accepted 20 January 2017
Available online 2 February 2017

Keywords:
Algorithm
Benchmarking
Construction project
Harmony Search
Resource Leveling Problem

ABSTRACT

The Resource Leveling Problem (RLP) aims to provide the most efficient resource consumption as well as minimize the resource fluctuations without increasing the prescribed makespan of the construction project. Resource fluctuations are impractical, inefficient and costly when they happen on construction sites. Therefore, previous research has tried to find an efficient way to solve this problem. Metaheuristics using Harmony Search seem to be faster and more efficient than others, but present the same problem of premature convergence closing around local optimums. In order to diminish this issue, this study introduces an innovative Improved and Adaptive Harmony Search (IAHS) algorithm to improve the solution of the RLP with multiple resources. This IAHS algorithm has been tested with the standard Project Scheduling Problem Library for four metrics that provide different leveled profiles from rectangular to bell shapes. The results have been compared with the benchmarks available in the literature presenting a complete discussion of results. Additionally, a case study of 71 construction activities contemplating the widest possible set of conditions including continuity and discontinuity of flow relationships has been solved as example of application for real life construction projects. Finally, a visualizer tool has been developed to compare the effects of applying different metrics with an app for Excel. The IAHS algorithm is faster with better overall results than other metaheuristics. Results also show that the IAHS algorithm is especially fitted for the Sum of Squares Optimization metric. The proposed IAHS algorithm for the RLP is a starting point in order to develop user-friendly and practical computer applications to provide realistic, fast and good solutions for construction project managers.

1. Introduction

Project scheduling problems (PSP) are NP-Hard optimization problems that comprise resource-constrained problems (RCPSP) and Resource Leveling Problems (RLP) among others [10,27,32]. In the former, resources are considered a constraint, and in the latter, the problem is the efficiency in resource consumption. Both problems are similar but of different natures. The RCPSP is a regular problem with the objective of minimizing the project makespan without exceeding the resource availability. The RLP is a non-regular problem with the objective of providing the most efficient resource consumption and reducing the resource fluctuations without increasing the prescribed makespan of the project.

Resource fluctuations are impractical, inefficient and costly when they happen on construction sites [13,24]; therefore, increasing the efficiency of the project sequence is one key factor to achieve the project goals [9]. In order to measure the efficiency of the project sequence, different metrics for the objective function have been proposed along the literature [8]. The first and most common objective function is the so called minimum squares optimization method or Sum of Squares Optimization (SSQR) method, which aims to provide an ideal uniform shape, minimizing the sample variance of resources consumption.

In construction projects a bell-shaped resource profile would be better from a practical point of view [37], so other metrics have been proposed by El-Rayes & Jun ([13,14]. The first authors proposed the Resource Idle Days and Maximum Daily Resource Demand Method to provide nearly gauss shape, eliminating the resources' idle periods. Florez, Castro-Lacouture, & Medaglia [14] proposed maximizing labor stability, aiming to increase the extent of use of workers and job continuity, and minimizing the maximal fluctuation of workers and the sum of the fluctuations.

Exact algorithms based upon enumeration, integer programming or mixed integer programing have been proposed to offer optimal solutions, but this kind of problems have a phenomenon of "combinatorial explosion" or rapid non-polynomial increase in the number of possible solutions, especially for large strong problems [32]. Although these

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http://dx.doi.org/10.1016/j.autcon.2017.01.018
0926-5805/

algorithms produce the absolute optimum to a given problem, they are only functional from a practical point of view for small problems, as they require a vast computational capability and complex parallel processing of the network graph [31].

Alternative heuristic algorithms have been proposed to find near optimal solutions in an acceptable computational effort as the Burguess & Killebrew [4] algorithm, or the Minimum Moment (MOM) and Packing Method (PACK) proposed by Harris in 1978 and 1990 respectively. When the complexity of the problem increases, heuristic approaches fail to produce near optimum solutions, arising nature inspired algorithms, known as metaheuristics that apply smart searching strategies over a population of solutions (population-based) or evaluating only one potential solution (neighborhood-based) [35].

Numerous metaheuristics have been developed in the past years to solve complex optimization models. A new family of population-based metaheuristic inspired on the composition and improvisation process of jazz musicians, known as Harmony Search (HS) [17], has acquired special relevance. Harmony is synonymous to proper rhythm, the opposite of the dissonance and the anarchy; in other words, harmony seeks to provide the sequence of sounds that best fit with an ideal of sonorous beauty, or its equivalent in optimization problems, an objective function represented by a metric of efficiency.

Harmony Search (HS) seems to be faster and more efficient than other metaheuristics [28] avoiding the premature convergence and relapse into local optimums, but proposals with the application of HS algorithms in construction project scheduling are still scarce and limited to small projects. Aiming to prove the goodness of Harmony Search (HS) algorithms in construction project scheduling problems, this research adapts the Improved Harmony Search algorithm proposed by Chakraborty et al. [6], taking into consideration the adaptive adjustment of parameters proposed by Mahdavi et al. [25] in an Improved and Adaptive Harmony Search (IAHS) algorithm. This IAHS algorithm is tested solving the j30, j60 and j120 instances of the Project Scheduling Problem Library (PSPLIB) [23] for four different metrics, comparing the obtained results with benchmarks available in the literature. Additionally, as case study of a real life construction projects, a building project of 15 floors [30,31], is used to illustrate the versatility and adaptability of the proposed IHSA for the four objective functions analyzed in this research.

2. Literature review of the RLP

The first contribution to solve the RLP to optimality was proposed by Petrovic [29]. It was later improved by Bandelloni et al. [2], applying dynamic programming with precedence constraints. After that, Ahuja [1] exposed an enumeration method to compute all the combinations of the activities" starting times for the minimum lags problem. Applying mixed binary-integer programming, Easa [11] proposed the first know formulation based on the Pritsker et al. [33] model for the RCPSP in which the solution is presented by binary variables that represent the finishing period of the tasks. Rieck et al. [34] introduced the domain-reducing pre-processing technique for the mixed-integer formulation. Hariga and El-Sayegh [20] improved the classical mixed binary-integer model allowing the activity splitting minimizing its associated costs. Ponz-Tienda et al. [32] developed two different binary optimization models, based on decision variables that establishes the period in which the activities are finished and executed respectively. More recently, the same authors proposed a Parallel Branch and Bound (B&B) [31] algorithm, solving to optimality 50 instances of the PSPLIB (with complexity from 10^8 to 10^{18}) for the RLP with minimal lags for the first time using an acceptable computational effort. Proposals to reduce the set of feasible solutions, branching the nodes in order to solve the problem approximately, were suggested by Neumann and Zimmermann [27], Mutlu [26] and Gather et al. [16].

The RLP, as an NP-Hard problem, has a phenomenon of "combinatorial explosion" [32] and exact algorithms are only efficient for small projects. To avoid this problem, different heuristic procedures have been proposed along the literature to provide local optimal against global optimal solutions. The first heuristic procedure for the RLP was proposed by Burgess and Killebrew [4], establishing the Sum of Squares Optimization metric as the performance measure. The Burgess and Killebrew algorithm presents some inefficiencies that were solved by Burman [5] using the free float as the limit for the activity shifting. Other sound proposals are the Minimum Moment (MOM) algorithm [21] and the packing method (PACK) [22].

As alternative to heuristic procedures, metaheuristic algorithms are higher-level procedures designed to find sufficiently good solutions to an optimization problem with limited computation capacity. Metaheuristic algorithms are grounded in physical, biological and animal behaviour, such as Greedy Randomized Adaptive Search Procedure (GRASP), evolutionary algorithms (EA), genetic algorithms (GA), tabu search (TS), simulated annealing (SA), ant colony optimization (ACO), particle swarm optimization (PSO), shuffled frog-leaping (SFL), the grenade explosion (GE) method, or more recently the harmony search (HS), a population-based metaheuristic algorithm, proposed by Geem et al. [17].

3. Research justification, goal and process

Construction activities need to be sequenced in a way that minimizes resource variability whereas optimize the project schedule sequences. This way, the Resource Leveling Problems (RLP) aims to minimize resource fluctuations. Previous authors [28] indicate that HS algorithm are faster and more efficient than other metaheuristics avoiding the premature convergence and relapse into local optimums. However, applications of the HS algorithm to scheduling problems are still scarce in the literature.

Therefore, the goal of this study is to prove the goodness of the HS algorithms in project scheduling problems, by means of adapting the HS algorithm proposed by Chakraborty et al. [6] with a variation of the adaptive adjustment of parameters proposed by Mahdavi et al. [25] in an Improved and Adaptive Harmony Search (IAHS) algorithm. The Improved and Adaptive Harmony Search will be tested solving the j30, j60 and j120 instances of the PSPLIB [23] for four different metrics, comparing the obtained results with benchmarks available in the literature. Additionally, the results of the computational experimentation, with 5760 solved instances from 30 to 120 activities, is generalized with a real case study of 71 construction activities contemplating the widest possible set of conditions including continuity and discontinuity of flow relationships also known as point-to-point relationships. In order to fulfill this goal, this study follows the following process:

1. Literature review on the RLP (summarized in the previous section).
2. After stating the Resource Leveling Problem with minimal time lags in the next section, the proposal of an algorithm for the Improved and Adaptive Harmony Search (IAHS henceforth) for the RLP with multiple resources is introduced in the sub-sequent section.
3. The rationale of the IAHS is confirmed through computational experimentation as well as a benchmarking test.
4. Finally, a real case study (with 71 construction activities) is used to show the applicability of the IAHS proposal.

4. Problem statement of the RLP

For a complete comprehension of the remainder of the paper, some elements and the general formulation of the RLP based on activity-on-node networks with minimal finish-to-start relationships should take into consideration:

1. The set N of activities (being n the total number of activities that must be executed with constant intensity and without interruption, and