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Discrete Optimization

Integration of electromagnetism with multi-objective evolutionary algorithms for RCPSP

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ABSTRACT

As one of the most challenging combinatorial optimization problems in scheduling, the resource-constrained project scheduling problem (RCPSP) has attracted numerous scholars' interest resulting in considerable research in the past few decades. However, most of these papers focused on the single objective RCPSP; only a few papers concentrated on the multi-objective resource-constrained project scheduling problems (MORCPSP). Inspired by a procedure called electromagnetism (EM), which can help a generic population-based evolutionary search algorithm to obtain good results for single objective RCPSP, in this paper we attempt to extend EM and integrate it into three reputable state-of-the-art multi-objective evolutionary algorithms (MOEAs) i.e. non-dominated sorting based multi-objective evolutionary algorithm (NSGA-II), strength Pareto evolutionary algorithm (SPEA2) and multi-objective evolutionary algorithm based on decomposition (MOEA/D), for MORCPSP. We aim to optimize makespan and total tardiness. Empirical analysis based on standard benchmark datasets are conducted by comparing the versions of integrating EM to NSGA-II, SPEA2 and MOEA/D with the original algorithms without EM. The results demonstrate that EM can improve the performance of NSGA-II and SPEA2, especially for NSGA-II.

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1. Introduction

The research on the classical resource-constrained project scheduling problem (RCPSP) has been widely expanded over the past several decades. According to the reviews provided by Herroelen, Demeulemeester, and Reyck (1999, chap. 1), Brucker, Drexl, Möhring, Neumann, and Pesch (1999), Icmeli, Erenguc, and Zappe (1993), Kolisch and Padman (2001) and ÖZdamar and Ulusoy (1995), the RCPSP can be stated as follows. A set of activities N numbered from 0 to n is to be scheduled without preemption. Activity i has a duration d_i and needs some resources which are limited during every moment to be completed. We assume that the renewable resource set is R and the availability of each resource type k, $k \in R$, which is a constant a_k throughout the project horizon. Each activity i needs r_{ik} units of resource k during each period of its duration, $i \in N$, $k \in R$. The dummy start and end activities 0 and n have zero duration and do not require any resource. The precedence relation among the activities is that one activity cannot be started until all its predecessors have been finished. A solution for RCPSP is feasible if and only if the precedence and resource constraints are satisfied. In general, a solution of RCPSP is represented as a schedule or a list of start times $s = (s_0, \ldots, s_n)$ that implies a corresponding finishing times $f = (f_0, \ldots, f_n)$. Obviously, as every manager usually wants to finish projects as quickly as possible with minimum cost and high quality, RCPSP is a multi-objective optimization problem. Słowiński (1981) is the first to describe the multi-objective resource-constrained project scheduling problem (MORCPSP) framework and list all kinds of objectives. After the further research on MORCPSP, the primary objectives include makespan, activity tardiness, net present value (NPV), resource investment (RI), and robustness. MORCPSP is strongly NP-hard.

As one kind of the most effective algorithms used for solving NP-hard problems, metaheuristic algorithms have been developed and proved to be successful in practice. Certainly many multi-objective metaheuristic approaches named MOEAs (multi-objective evolutionary algorithms) have been developed rapidly and applied for multi-objective optimization problems widely. Fonseca et al. (1993) proposed multi-objective genetic algorithm (MOGA); Srinivas and Deb (1994) proposed non-dominated sorting genetic algorithm (NSGA) and Horn, Nafpliotis, and Goldberg (1994) proposed niched Pareto genetic algorithm (NPGA). These algorithms were generally classified as the first generation of MOEAs in which selecting individuals based on Pareto ranks and maintaining population diversity by fitness sharing were the common features. The second generation of MOEAs based on elitism strategy has been proposed successively since 1999. Zitzler and Thiele (1999) presented Strength Pareto

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Evolutionary Algorithm (SPEA) and the improved version SPEA2 was described in Zitzler, Laumanns, and Thiele (2001). Pareto Archived Evolution Strategy (PAES) was proposed by Knowles and Corne (2000). Pareto Envelope-Based Selection Algorithm (PESA) and its improved version of PESA-II were introduced in Corne, Knowles, and Oates (2000) and Corne, Jerram, Knowles, and Oates (2001) respectively. Erickson, Mayer, and Horn (2001, chap. 48) advanced NPGA2, and the famous NSGA-II was proposed by Deb, Pratap, Agarwal, and Meyarivan (2002). On the other hand, Zhou, Zhang, Jin, Sendhoff, and Tsang (2007) presented Regularity Model Based Multi-objective Estimation of Distribution Algorithm (RM-MEDA), and Zhang and Li (2007) introduced Multi-objective Evolutionary Algorithm Based on Decomposition (MOEA/D) by combining traditional mathematical programming with evolutionary algorithms.

Even though the MOEAs of the second generation have been proved to be successful in handling multi-objective optimization problems with high performance, only a few MOEAs such as NSGA-II have been used for dealing with MORCPSP. Meanwhile, many excellent hybrid algorithms have been presented and applied for classical single objective RCPSP successfully. As the electromagnetism (EM) heuristics has been applied for many unconstrained global optimization problem, Debels, De Reyck, Leus, and Vanhoucke (2006) extended the electromagnetism heuristics and integrated it into a scatter search (SS) frame for single objective RCPSP. By utilizing the principle that the EM force generated by two solutions would guide the search direction, scatter search integrated with EM outperformed other state-of-the-art heuristics for single objective RCPSP in this literature. However, to the best of our knowledge, no paper was found in literature integrating EM heuristics into MOEAs to solve MORCPSP. Inspired by the method presented by Debels, we modify the EM heuristics to make it suitable for MORCPSP and combine it with several state-of-the-art MOEAs i.e. NSGA-II, SPEA2 and MOEA/D in this paper.

The paper is organized as follows: in Section 2, a literature review is presented. In Section 3, some basic concepts concerning MORCPSP are introduced. Then the representation and evaluation measurements for MORCPSP are defined in Section 4. In Section 5, we show how the EM methodology can be modified to be used for MORCPSP. Brief introductions of NSGA-II, SPEA2, MOEA/D and the method of integrating EM heuristics into the three algorithms are given in Section 6. Section 7 shows experimental results and comparison analysis. Finally, some concluding remarks are given in Section 8.

2. Literature review

Słowiński (1981) presented the first multi-objective RCPSP framework that applied multi-objective linear programming to a MORCPSP with splittable activities, multiple modes, renewable, non-renewable and doubly constrained resources. It is notable that this procedure belonged to single objective optimization process actually because it could only optimize one objective each time. Furthermore, Słowiński, Soniewicki, and Węglarz (1994) proposed a decision support system to optimize several objectives including project completion time, smoothness of the resource profile, total resource consumption, weighted resource consumption, weighted flow time and net present value by using parallel priority rules, simulated annealing, branch and bound. Hapke, Jaszkiewicz, and Slowinski (1997) considered a multi-mode project scheduling problem under multi-category resource constraints with fuzzy time parameters of activities. A metaheuristic procedure Pareto simulated annealing (PSA) was presented to generate approximation solutions. Hapke, Jaszkiewicz, and Słowiński (1999, chap. 16), Pan and Yeh (2003, chap. 145) conducted the similar research. These three papers employed PSA frequently, and were partial to the fuzzy version of MORCPSP. Hapke, Jaszkiewicz, and Słowiński (1998) proposed a two-stage interactive search over a non-dominated solution space to handle a multiple-criteria PSP with multiple modes, renewable, non-renewable and doubly constrained resources. In order to optimize makespan, resource utilization smoothness, maximum lateness, NPV and project cost, in the first stage the approach applied PSA to generate a large representative sample of approximately non-dominated schedules. An iterative search over the sample based on the discrete version of the Light Beam Search (LBS) procedure was organized in the secondary stage.

Nabrzyski and Węglarz (1995) described a decision support system that could generate a set of feasible schedules using tabu search (TS) for individual criteria. In Nabrzyski and Węglarz (1999, chap. 17), they presented a knowledge-based multi-objective project scheduling system that handled a class of non-preemptive scheduling problems. The system made decisions during search. The optimization procedure was separated into several steps, and the trade-off solutions generated by each step guided the next step. These two models proposed by Nabrzyski considered the similar objective functions to Hapke et al. (1998), but difficult to obtain enough non-dominated solutions. In order to minimize the makespan, the “weighted” lateness of activities and the violation of resource constraints, Viana and Pinho de Sousa (2000) applied multi-objective versions of simulated annealing (MOPSA) and tabu search (MOTS) to RCPSP. In consequence of the absence of resource constraints, the procedure generated different schedules; it seemed difficult to obtain excellent solutions for medium or large instances in various performance measurements. Al-Fawzan and Haouari (2005) took two objectives of makespan and robustness (maximize the sum of the free slack of activities) into account. A MOTS that ran a single-objective TS with a different linearly aggregated function several times was implemented for this model. The approach could obtain good solutions in terms of makespan while one of the drawbacks was that it would probably miss the solutions with good performance for robustness but not good enough at makespan. Abbasi, Shadrokh, and Arkat (2006) aggregated two objectives of minimizing makespan and maximizing robustness into a linear objective and applied SA to solve it.

Most of the aforementioned papers applied SA and TS to solve MORCPSP, but failed to obtain enough Pareto solutions. Apart from the methods motioned above, other algorithms have been used to solve MORCPSP. Kazemi and Tavakkoli-Moghaddan (2008) presented a mathematical model for MORCPSP with discounted cash flows that aimed at minimizing makespan and maximizing net present value. Due to the computational complexity of MORCPSP, the software proposed for solving the model only could handle the test instances with small number of activities and resources. NSGA-II was applied to this model for the same test instances as well. Aboutalebi, Najafi, and Ghorashi (2012) compared the performance of NSGA-II and Multi-objective Particle Swarm Optimization (MOPSO) for the bi-objective RCPSP. The adopted objectives were the minimization of project makespan and maximization of net present value. The computation result demonstrated the superior performance of NSGA-II in terms of metric C and maximum spread metric. Ballestín and Blanco (2011) focused on the theoretical study and gave some proof for MOPSP with regular objective functions(ROFs). Comparisons among NSGA-II, SPEA2 and PSA in several performance measures were presented. However, the representation of a solution was complicated and the measures to evaluate the quality of a solution obtained by algorithms were intricate because of all kinds of artificial parameters. Wang, Fang, Mu, and Liu (2013) presented a Pareto-archived estimation-of-distribution algorithm (PAEDA) for the multi-objective resource-constrained project scheduling problem with makespan and resource investment criteria. The numerical experiment results showed that the PAEDA outperformed the existing methods. Gomes, de Assis das Neves, and Souza (2014) implemented five multi-objective metaheuristic algorithms, based on multi-objective GRASP (MOG), multi-objective variable neighborhood search (MOVNS), a MOG using NVS as local search (GMOVNS), a MOVNS with an intensification

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