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A multi-objective invasive weeds optimization algorithm for solving multi-skill multi-mode resource constrained project scheduling problem

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ABSTRACT

A new multi-skill multi-mode resource constrained project scheduling problem with three objectives is studied in this paper. The objectives are: (1) minimizing project's makespan, (2) minimizing total cost of allocating workers to skills, and (3) maximizing total quality of processing activities. A meta-heuristic algorithm called multi-objective invasive weeds optimization algorithm (MOIWO) with a new chromosome structure guaranteeing feasibility of solutions is developed to solve the proposed problem. Two other meta-heuristic algorithms called non-dominated sorting genetic algorithm (NSGA-II) and multi-objective particle swarm optimization algorithm (MOPSO) are used to validate the solutions obtained by the developed MOIWO. The parameters of the developed algorithms are calibrated using Taguchi method. The results of the experiments show that the MOIWO algorithm has better performance in terms of diversification metric, the MOPSO algorithm has better performance regarding mean ideal distance, while NSGA-II algorithm has better performance in terms of spread of non-dominance solution and spacing metrics.

1. Introduction

The resource constrained project scheduling problem (RCPSP) is aimed to find appropriate start/finish time of activities regarding perquisite relations and resource constraints. This NP-Hard problem was firstly introduced by Blazewicz et al. (1983). Recently, Kopanos et al. (2014) developed two discrete-time and two continuous-time formulations for the RCPSP. Multi-mode version of RCPSP (MRCPSP) is an extension of RCPSP with more than one mode to perform each activity, where the problem is to select the best performing mode of each activity and to determine the schedule optimizing the objective(s) of the model.

As maximizing quality along with minimizing time and cost is a crucial aim in most of industrial and construction projects, time-cost-quality trade-off problem (TCQTP) has attracted many researchers. El-Rayes and Kandil (2005) developed a multi-objective time-cost-quality problem for construction projects to support project managers considering time, cost and quality factors in their decision making process. They also used a genetic algorithm to solve the proposed problem. Afshar et al. (2007) presented a three objective TCQTP and developed a new multi-colony ant optimization algorithm to solve the resulting problem. ShahsavariPour et al. (2010) formulated a bi-objective multi-mode model for TCQTP considering a quality constraint to guarantee that the project quality will be always higher than a predefined level. Zhang and Xing (2010) proposed a fuzzy multi-objective TCQTP. They used a fuzzy multi-objective particle swarm optimization algorithm to solve the problem.

Recently, planning and scheduling problems has gained important contribution in process industries including continuous and batch production modes. Marchetti and Cerdá (2009) proposed an approximate resource constrained continuous-time formulation for multistage batch facilities. Kopanos et al. (2011) presented a mixed-integer linear programming framework for the resource-constrained production planning problem in semi-continuous food processes. Koné et al. (2013) extended RCPSP taking into account storage resources that can be produced or consumed by activities. Novara et al. (2013) proposed an efficient constraint programming (CP) approach to the short-term scheduling problem of multi-stage batch plants with different objective functions. Carvalho et al. (2015) presented an optimal planning and scheduling model based

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on the resource task network. Chakrabortty et al. (2016) developed a real-time disruption recovery plan for MRCPSP.

Contribution of the presented work in this paper is threefold: first, multi-skill MRCPSP is integrated with discrete time-cost-quality trade-off (DTCQTP), in order to tackle one of the key drawbacks of previous research. In doing so, a new three-objective multi-skill MRCPSP-DTCQTP model with the aims of minimizing project cost and time along with maximizing quality is presented. Second, a multi-objective invasive weeds optimization algorithm (MOIWO) with a new chromosome structure is developed to solve the problem. Finally, the effectiveness of the proposed MOIWO is analyzed in comparison with the other two solving approaches, i.e. NSGA-II and MOPSO, based on some test problems.

The remainder of the paper in organized as follows: Section 2 is devoted to the problem description and mathematical formulation of the proposed multi-objective problem. Section 3 describes the developed MOIWO algorithm to solve the problem. Computational results are included in Section 4. Finally, Section 5 concludes the paper.

2. Problem formulation

Discrete time-cost trade-off problems (DTCTP) is one of the popular issues in project management literature, which was firstly introduced by Hindelang and Muth (1979). The DTCTP is a strictly complex problem and exact algorithms cannot solve it in large scale sizes (Deıneko and Woeginger, 2001). Wuliang and Chengen (2009) extended the discrete time-cost trade off problem to a new multi-mode resource constrained project scheduling problem considering a constraint to preserve the upper bound of the project budget. There are heuristic algorithms such as multi-pass algorithm (Ahn and Erenguc, 1998), and meta-heuristic algorithms such as particle swarm optimization (Yang, 2011) and simulated annealing (Anagnostopoulos and Kotsikas, 2010) in the literature to solve this strictly NP-Hard problem. Tavana et al. (2014) developed a preemptive multi-mode multi-objective model for TCQTP. They proposed an efficient version of the ε-constrained method and dynamic self-adaptive multi-objective evolutionary algorithm to solve the proposed problem. Mungle et al. (2013) proposed a fuzzy-clustering based genetic algorithm to solve the three objective TCQTP. Monghasemi et al. (2015) developed a multi-objective TCQTP. They also used a MCDM method to find the best Pareto solution of the problem. Afruzi et al. (2014) extended a TCQTP with mode identity structure and developed a multi-objective imperialist competitive algorithm to solve the problem. They also assumed that each activity can be performed in either crashed or normal way. In addition to TCQTP, MRCPSP models have been investigated widely in the literature (see Table 1), where multi-skill man-power resources has gained increasing popularity nowadays.

In this section, a novel three-objective multi-skill MRCPSP-DTCQT model is proposed to: (1) determine the optimal mode of performing each activity, (2) determine the optimal start time of each activity, and (3) assign the optimal skill of each resource. In this regard, a mixed-integer programming is used to formulate the problem. The time-based objective of the model is minimizing the project make-span. The cost-based objective is to minimize the cost of assigning project workforces to the required skills. The quality-oriented objective of the model is maximizing the total quality of the project defined as the weighted sum of the qualities of the activities. In what follows, the assumptions and other requirements of the model are defined.

2.1. Assumptions

Activities are numbered topologically with 0 and $N+1$ as dummy start and end activities.
All multi-skill resources used in the project are manpower and are always available.
Each activity may be executed in several modes and may need various skills.
Preemption is not allowed during execution of an activity.
During execution of each activity, the assigned mode cannot be changed.
Each manpower performs an activity with a pre-defined duration, cost, and quality.
Each manpower cannot be allocated to more than one skill of an activity at the same time.
All required skills for performing an activity should start their jobs simultaneously.

2.2. Indices

i, j: index of activities	$i, j = 0, 1, 2, \ldots, N, N+1$
m: index of execution modes	$m = 1, 2, \ldots, M$
k: index of skills	$k = 1, 2, \ldots, K$
s: index of workforces	$s = 1, 2, \ldots, S$

2.3. Parameters

V:	set of activities
A:	set of finish to start perquisite relations
E:	set of skills
W_i:	weight of activity i
P_{im}:	duration of activity i in mode m
C_{sk}:	cost of performing skill k by workforce s per unit time
q_{sk}:	quality of executing skill k by workforce s
b_{imk}:	the required number of workforces for performing skill k of activity i in mode m
T:	upper bound of project's makespan
$r_{sk} = 1$	if workforce s has skill k; 0 otherwise

Table 1
A summary of recent works on the MRCPSP.

Author(s)	Problem features	Solution approach
Ulusoy et al. (2001)	Discounted cash flows	Genetic algorithm
Heilmann (2001)	Minimum and maximum time lags	Multi-pass heuristic
Heilmann (2003)	Minimum and maximum time lags	Branch and bound
Buddhakulsomsiri and Kim (2006)	Activities can be interrupted	Branch and bound
Mika et al. (2008)	Schedule-dependent setup times	Tabu search algorithm
Sabzehparvar and Seyed-Hosseini (2008)	Mode-dependent time-lags	OR soft wares
Van Peteghem and Vanhoucke (2010)	Preemptive	Genetic algorithm
Kyriakidis et al. (2012)	Resource-task network representation	OR soft wares
Baradaran et al. (2012)	PERT environment	Hybrid scatter search
Bagherinejad and Majd (2014)	Tardiness and earliness	Genetic algorithm
Afshar-Nadjafi (2014)	Mode changed after preemption	Simulated annealing
Wang and Fang (2012)	Basic MRCPSP	EDA
Wang and Fang (2011)	Basic MRCPSP	Shuffled frog leaping
Li and Zhang (2013)	Renewable and nonrenewable resource	Ant colony optimization
Afshar-Nadjafi and Majlesi (2014)	Setup times after preemption	Genetic algorithm