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A hybrid TLBO-TS algorithm for integrated selection and scheduling of projects

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ABSTRACT

Organizations dealing with projects often face the challenge of choosing right mix of projects for implementation and scheduling. The two steps have, however, traditionally been performed in sequential manner often resulting into problems such as scope changes/dropping/replacement/delayed completion of the projects. This paper deals with the problem of simultaneous selection and scheduling of the projects with maximization of total expected benefit of the portfolio as an objective. Expected benefit of the project is considered to be time sensitive. Further, the projects have a variety of interdependencies between them. Two types of interdependencies: mutual exclusiveness and complementariness have been considered. A zero-one integer programming model is proposed for the problem. Three meta-heuristics: TLBO, TS and hybrid TLBO-TS have been developed and compared with the existing algorithms in the literature. The performance of the algorithms is evaluated on the four different types of data sets. Performance of the hybrid TLBO-TS algorithm has been found to be quite promising in terms of solution quality and convergence.

1. Introduction

Organizations dealing with multiple projects often face the challenge of selection and scheduling of optimal mix of projects. The traditional project selection exercise seeks to first select the portfolio of projects from a set of candidate projects and then schedule the selected projects respecting the resource, budget and other constrains. This sequential approach, however, may lead to difficulty in scheduling the selected portfolio during given time frame resulting in scope changes/dropping/replacement/delayed completion of some of the projects. Alternatively, availability of the resources may need to be increased or time frame for the projects has to be extended. Thus, the selection and scheduling of projects in sequential manner result into sub-optimality (Coffin & Taylor, 1996a, 1996b). Hence the scheduling needs to be considered as an integral part of the project selection process. This joint problem is termed as the project portfolio selection and scheduling problem (PPSSP) in literature. The PPSSP can be stated as the simultaneous problem of selection and scheduling of projects to optimize organization's stated objectives in specified time horizon without violating budget and resource constraints (Chen & Askin, 2009).

The PPSSP has been studied for a variety of objectives with maximizing the overall benefit being the most common objective (Coffin & Taylor, 1996a, 1996b; Amirian & Sahraeian, 2017; Bhattacharyya, Kumar, & Kar, 2011; Chen & Askin, 2009; Ghorbani & Rabbani, 2009; Huang & Zhao, 2014; Shou, Xiang, Li, & Yao, 2014; Tofighian & Naderi, 2015; Tseng & Liu, 2011). The overall benefit to an organization, however, is time dependent as the earlier completion of a project is generally more beneficial. Consider, for example, IT projects where new gadgets are introduced in the market almost every day. Delayed introduction of a gadget may lead to reduced market share and hence profitability. This aspect of time dependent returns in project selection and scheduling has been considered by Chen and Askin (2009), Ghorbani and Rabbani (2009), Tofighian and Naderi (2015) and Amirian and Sahraeian (2017).

The candidate projects for selection often exhibit a variety of interdependencies. Interdependencies are present if inclusion/exclusion of a project in the portfolio is affected by the selection of other candidate project(s). Consideration of interdependencies yields more profit as the total benefit/cost from interdependent projects is not same as the sum of the individual project's benefit/cost. Aaker and Tyebjee (1978) and Fox, Baker, and Bryant (1984) were the pioneers who considered project interdependencies during project selection. Later on, project interdependencies in project selection have been considered e.g. by Li, Fang, Guo, Deng, and Qi (2016), Abbassi, Ashrafi, and Tashnizi (2014), Bhattacharyya et al. (2011), Liesiö, Mild, and Salo (2008), Lee and Kim (2000), Santhanam and Kyparisis (1996). Out of the various types of interdependencies between the projects mutual exclusiveness is considered the most in the literature. Projects are said to be mutually

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exclusive if only one project from the set can be included in the portfolio. Ghasemzadeh, Archer, and Iyogun (1999) were probably the first to consider mutual exclusiveness of projects and developed a 0–1 integer linear programming model for PPSSP. Ghorbani and Rabbani (2009) offered a multi-objective meta-heuristic to obtain the diverse non-dominated solutions for the joint problem of selection and scheduling considering mutually exclusive projects. Tofighian and Naderi (2015) consider the same problem and developed a multi-objective ant colony optimization for PPSSP. In addition to mutual exclusiveness of projects, Jafarzadeh, Tareghian, Rahbarnia, and Ghanbari (2015) and Wang and Song (2016) consider reinvestment strategy and Carazo et al. (2010), Huang and Zhao (2014), Huang, Zhao, and Kudratova (2016) consider uncertain project parameters such as net income and investment cost.

The resource constrained project scheduling problems (RCPSP) have already been identified as NP-hard in the literature (Demeulemeester & Herroelen, 2006). Thus, integration of selection with consideration of project interdependencies and scheduling makes it even more complex hence determining an optimal solution within reasonable time is very difficult. Ghasemzadeh et al. (1999), however, developed an ILP for PPSSP with project interdependencies which is suitable for small sized problems only and not for large size real life problems. Thus, meta-heuristic approaches have been developed. Meta-heuristics are efficient, flexible and independent of the problem and model. Ghorbani and Rabbani (2009) developed a multi-objective scatter search algorithm to solve the multi-objective project selection and scheduling problem. Shi, Wang, and Qi (2011) proposed a genetic algorithm to maximize the overall net present value of R&D projects. Tofighian and Naderi (2015) proposed an ant colony optimization algorithm to maximize total expected benefit of the selected projects and to minimize resource usage variation. Amirian and Sahraeian (2017) considered grey parameters and proposed a modified grey shuffled frog leaping algorithm (GSFLA). Shariatmadari, Nahavandi, Zegordi, and Sobhiyah (2017) proposed an integrated resource management approach and developed a Gravitational Search Algorithm (GSA) for the problem.

The review of literature reveals that mutual exclusiveness has been considered as project interdependencies in the PPSSP. There is, however, another important interdependency – complementariness – yet, ignored in the existing literature. The projects are said to be complimentary if the entire subset of the projects is selected or rejected together (Fox et al., 1984). For example, if two projects A and B are complementary then A and B must be selected or rejected together. The complementariness can be observed in many real life situations. Consider, e.g. electricity generation and transmission projects. In this situation construction of power plant and laying of transmission lines could be two projects which needs to be selected or rejected together. Take another example where a municipal corporation is going for cleanliness drive in which one project is development of system for waste collection and the other is making the user aware through awareness campaign. The real benefit from the drive could only be achieved when both of the projects are selected. Similar examples of complementarity of projects can be found in research & development, automotive industry, and information system organizations etc.

A variety of meta-heuristic approaches such as genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), simulated annealing (SA), tabu search (TS) and artificial bee colony (ABC) have been developed for solving large number of engineering and management problems. Teaching learning based optimization (TLBO) is one of the recently developed meta-heuristic which has been successfully applied to a variety of complex optimization problems (Baykasoğlu, Hamzadayi, & Köse, 2014; Dokeroglu, 2015; Keesari & Rao, 2014; Rao & Patel, 2012; Tuncel & Aydin, 2014; Xu, Wang, Wang, & Liu 2015; Yu, Wang, & Wang, 2016;) with the benefit of very less number of parameters to be tuned compared to other meta-heuristics.

The current paper considers the problem of PPSSP with two types of interdependencies: mutual exclusiveness and complementariness. A modified TLBO algorithm has been proposed for the problem. In order to improve the performance of the algorithm the hybridization of the TLBO with well-known tabu search algorithm is proposed. The proposed algorithms are tested on four different complexity level data sets generated in this research. Performance of the proposed algorithms has been compared with the existing algorithms available in the literature for the problem. The results are quite promising. The current research contributes to the existing body of the knowledge in terms of consideration of complementarity of projects in integrated project selection & scheduling and development of new meta-heuristic algorithms for solving the problem.

The remaining of this paper has been organized in the following manner. Section 2 proposes an improved mathematical model for the PPSSP. In Section 3 the methodology for the proposed algorithms has been described. The scheme for test problem generation, parameter settings for the proposed algorithms, results obtained and performance of the algorithms is discussed in Section 4. The paper is concluded in Section 5.

2. Problem definition and mathematical formulation

This section presents a zero-one integer linear programming model for the PPSSP and an illustrative example for the same. Let, there be a set of N projects out of which a subset of projects is to be selected optimally respecting resource availability constraints and interdependencies. The projects may have two types of interdependencies among them viz. mutual exclusiveness and complementariness. K types of renewable resources are needed to carry out the portfolio of the selected projects in a planning horizon spanning T time periods. The resources are available in limited quantity during each period of the planning horizon. The objective of the problem is to maximize the total expected benefit from selected portfolio of projects. The expected benefit from a project is considered to be time dependent. This means delay in the implementation of a project will lead to a decrease in expected benefit.

2.1. Mathematical model

A formal mathematical model, its decision variables and coefficients are as below:

Decision variable:

X_{it} 1; if project i is selected and starts in period t,
0 otherwise.

Technological coefficients and parameters:

N number of candidate projects; $(i = 1, 2, \dots, N)$
K number of resource types; $(k = 1, 2, \dots, K)$
T time periods; $(t = 1, 2, \dots, T)$
P_{it} expected profit if project i starts in period t.
d_i duration of the project i.
r_{ik} requirement of resource type k for project i in each time period.
R_{kt} resource availability of type k in period t.
h project which is complementary to project i.
H_i set of projects which are complementary to i.
e project mutually exclusive to project i.
E_i set of projects mutually exclusive to project i.

Formulation:

Objective function:

$$\text{Max} \quad \sum_{i=1}^{N} \sum_{t=1}^{T-d_i+1} P_{it} * X_{it} \tag{1}$$

Constraints:

$$\sum_{t=1}^{T-d_i+1} X_{it} \leqslant 1 \quad \forall\, i \tag{2}$$