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Hybrid time-quality-cost trade-off problems

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ABSTRACT

Agile and hybrid project management has become increasingly popular among practitioners, particularly in the IT sector. In contrast to the theoretically and algorithmically well-established and developed time-cost and time-quality-cost project management methods, agile and hybrid project management lacks a principle foundation and algorithmic treatment. The aim of this paper is to fill this gap. We propose a matrix-based method that provides scores for alternative project plans that host flexible task dependencies and undecided, supplementary task completion while also covering traditional time-quality-cost trade-off problems. The proposed method can bridge the agile and traditional approaches.

1. Introduction

The importance of time-cost trade-off problems was recognized over five decades ago, with the nearly simultaneous development of project planning techniques [1]. From the 1960s to the 1980s, continuous time-cost relationship problems were addressed extensively in the literature [see, e.g., 2,3]. The discrete time-cost trade-off problem (DTCTP), which can be treated as a specific resource-allocation problem [4], is a well-known problem in the project management literature [see, e.g., [5–7]]. At first, Ref. [8] suggested that the quality of a completed project may be affected by project crashing. They developed a solution procedure that considers trade-offs among time, cost and quality in a continuous mode. Since discrete time-cost trade-off problems (DTCTP) are NP-hard problems, discrete time-quality-cost trade-off problems (DTQCTP) are also NP-hard problems and are therefore usually solved using heuristic or meta-heuristic methods. However, continuous versions of these problems can usually be solved within a polynomial computational time (e.g., in the case of linear trade-off functions between time-cost and time-quality) [9]. All of these problems assume a fixed-logic plan, whereas recent project management (e.g., agile and hybrid) approaches allow for the restructuring or reorganization of the project. They approaches apply flexible-logic plans instead of fixed-logic plans. This paper extends the traditional trade-off problem to address flexible project plans.

Continuous and discrete versions of time-cost and time-quality-cost trade-off analyses assume that the time, cost and quality of an option within an activity are deterministic. However, the time, quality and cost may be uncertain. The stochastic versions of time-cost and time-quality-cost trade-off problems [see, e.g., 10,11] treat time, quality and cost as uncertain parameters. In the proposed method, the task (e.g., time/cost/resource) demands are not uncertain, but the logical structure is. The proposed model can address uncertainty regarding supplementary task completion and/or uncertain or flexible dependencies.

It is interesting to combine uncertain task durations, uncertain cost demands, uncertain quality parameters (undecided), supplementary task completion and uncertain or flexible task dependencies into one stochastic model; however, this paper mainly focuses on how to extend continuous and discrete time-quality-cost trade-off methods to treat flexible dependencies and (undecided or uncertain) supplementary task completion.

Every traditional trade-off method assumes an accepted logic plan by which the tasks and the dependencies between them are determined. However, several project management approaches, e.g., agile and extreme project management (see Ref. [12]), allow for one to restructure or reorganize the project plan in response to changes in the client's demands.

Wysocki found in a 2009 study of the practices of software project managers that only 20% of IT projects were managed using a traditional project management (TPM) methodology. Methods for investment and construction projects usually cannot be directly applied to software development or R&D projects, as these are managed using agile project management (APM) approaches. Currently, hybrid (i.e., combinations of traditional and agile) approaches are becoming increasingly popular [see, e.g., 13,14]. However, these approaches lack a principled foundation and algorithmic treatment. The aim of this paper is to fill this gap.

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Whereas a project manager who follows a TPM approach uses TCTP/TQCTP method(s) to reduce task duration, an agile project manager tries to restructure the project. The project duration can be reduced without increasing the project cost by reducing the number of flexible dependencies. However, in real project situations, most dependencies are fixed; therefore, the TPM and APM approaches should be integrated.

There are different combinations of agile and traditional project management approaches [see, e.g., [13,15,16]]. However, to the best of our knowledge, there is no exact algorithm that can be used to in hybrid time-quality-cost trade-off problems. Nevertheless, production development and IT projects, such as introducing and setting up new information systems, may require that part of the project be reorganized, particularly in the development phase. However, decreasing the time demands of mandatory tasks may also be an important requirement. Neither the agile nor the traditional approach can address this situation properly. Traditional approaches, or network-based methods, assume static logic plans, but the reorganization of projects may produce insufficient reductions in project duration and/or supplementary tasks, and important tasks may be excluded from the project due to budget constraints and/or project deadlines. A hybrid project management (HPM) approach may combine the traditional and agile approaches; however, HPM approaches are not yet supported by project planning methods. The proposed algorithm combines the agile and traditional approaches. This method extends traditional time-cost and time-quality trade-off methods by allowing for the restructuring and reorganizing of projects.

The proposed hybrid time-cost and hybrid time-quality-cost trade-off models manage flexible project plans and allow us to restructure or reorganize these project plans to satisfy customer and management demands. In contrast to the traditional project scoring and selection methods, there is no need to specify all project alternatives to select the most desirable project scenario or the one with the shortest duration or lowest cost.

To handle flexible project plans, matrix-based techniques will be used instead of traditional network-based project planning techniques.

The basis of the proposed methods is a matrix-based method, the project domain matrix (PDM) [see 17]. The PDM is an n by m matrix, where n is the number of tasks, $m = n + t + c + q + r$, t is the number of possible durations, c is the number of possible (direct) costs, q is the number of possible quality parameters, and r is the number of possible resource demands of tasks.

The PDM has five domains. The first domain is the logic domain (LD), which is described as an n by n project expert matrix (PEM) [see 18] or numerical dependency structure matrix (NDSM)[see 19][1]. Since the PEM has specified and semi-specified versions, the PDM is *specified* if and only if the LD is specified; otherwise, the PDM is *semi-specified*.

The other domains are the time domain (TD), cost domain (CD), quality domain (QD) and resource domain (RD). If the demands are deterministic, we say that the PDM is *deterministic*; otherwise, the PDM is *non-deterministic*. In this study, the deterministic versions of hybrid time-quality-cost trade-off problems are considered: the TD, CD, QD, and RD contain deterministic values but at least two completion modes. Therefore, this version is a semi-specified, deterministic, multi-modal PDM.

Whereas the basis of the proposed model is the PDM, the basis of the proposed method is the expert project ranking (EPR) algorithm [see 17], which can evaluate specified and semi-specified deterministic PDMs. However, that method cannot address the trade-off problem. Therefore, although EPR can be used to schedule a flexible project plan and can thus be used in agile project management approaches, it cannot address trade-offs between time and cost or between time and quality and therefore cannot be used in hybrid project management directly.

This paper proposes a hybrid time-quality-cost trade-off model to bridge APM and TPM.

The proposed hybrid algorithm combines the features of EPR and time-quality-cost trade-off problems to solve hybrid time-quality-cost trade-off problems.

The proposed algorithm can be used not only for project planning but also for project risk management. Despite risk management and mitigation not being the main focus of this paper, in the section of the simulation beyond traditional risk management, in which project networks are usually assumed to have a fixed logic plan [20] or be a result of a negotiation [21], it was possible to measure the effect of the ratio of flexible dependencies and the ratio of uncertain (supplementary) task completions. The use of flexible dependencies and supplementary tasks enables us to model and compare different project management approaches.

The paper organized as follows: after this section, in Section 2, the mathematical background is described. In Section 3, we present the proposed algorithm, and different types of project management approaches are modeled and compared. In the last section (Section 4), we summarize the conclusions and discuss the limitations of the proposed algorithm and future directions.

2. Solving hybrid time-quality-cost trade-off problems

In this section, a (resource-constrained) hybrid time-quality-cost trade-off problem (RC-HTQCTP) is first specified. Then, a matrix-based model representation is proposed. At the end of this section, an exact algorithm for a hybrid continuous time-quality-cost trade-off problem is proposed. The decisions for finding the optimum will be directed by *score functions* and *matrices* (P, Q) and time-quality-cost functions; thus, we need several definitions and notations before proceeding.

2.1. Definitions and problem statements

In the proposed model, mandatory and supplementary activities are distinguished.

Definition 1. We call any finite set $A = \{a_1, \ldots, a_n\}$ the set of **possible activities** or **tasks** in the project. The subset of **supplementary task** is $\tilde{A} = \{\tilde{a}_1, \ldots, \tilde{a}_\sigma\} \subseteq A$, where $\tilde{A}$ is any fixed subset of A. Then, $\bar{A} = A \setminus \tilde{A}$ is the subset of **mandatory tasks**.

Whereas mandatory (or high-priority) tasks must be realized, supplementary (or lower-priority) tasks can be omitted from the project or postponed to the next or another project. Decisions about *supplementary* task realization always have two options: to include or to exclude.

S denotes the set of tasks that will be fulfilled by the algorithm (furthermore called as *project scenario*). The number of possible project scenarios is 2^σ, where $\sigma = |\tilde{A}|$.

Definition 2. Any function $P: A \to [0, 1]$ is called the **score function of** task**inclusion** if $P(a_i) = 1$ for $a_i \in \bar{A}$ and $P(a_i) \in [0, 1)$ for $a_i \in \tilde{A}$. The function $Q: A \to [0, 1]$ is called the **score function of** task **exclusion** if $Q(a_i) = 0$ for $a_i \in \bar{A}$ and $Q(a_i) \in (0, 1]$ for $a_i \in \tilde{A}$.

The task inclusion and exclusion scores can mean probability, importance or relative priority values.

Example 1. If every task completion (inclusion) score is a probability value, then $Q = 1 - P$.

Definition 3. For any associative and *monotone*[2] operation $\otimes$ on $\mathbb{R}^+$, we define the **aggregation function** $\otimes : \Xi(A) \to \mathbb{R}$ as

[1] The NDSM does not represent supplementary tasks but can represent flexible dependencies; however, the PEM can represent both flexible dependencies and supplementary tasks

[2] $\otimes$ is **monotone** if $x \le y$ and $u \le v$ implies $x \otimes u \le y \otimes v$ for $x, y, u, v \in \mathbb{R}^+$.