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An exact method for scheduling of the alternative technologies in R&D projects

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ABSTRACT

A fundamental challenge associated with research or new product development projects is identifying that innovative activity that will deliver success. In such projects, it is typically the case that innovative breakthroughs can be achieved by any of several possible alternative technologies, some of which may fail due to the technological risks involved. In some cases, the project payoff is obtained as soon as any single technology is completed successfully. We refer to such a project as alternative-technologies project and in this paper we consider the alternative-technologies project scheduling problem. We examine how to schedule alternative R&D activities in order to maximize the expected net present value, when each technology has a cost and a probability of failure. Although a branch-and-bound algorithm has been presented for this problem in the literature, we reformulate the problem and develop a new and improved branch-and-bound algorithm. We show using computational results that the new algorithm is much more efficient and outperforms the previous one.

1. Introduction

The development of complex and innovative products is characterized by much uncertainty. In order to deal with this uncertainty, it has been suggested that research and development (R&D) projects should pursue multiple alternative solutions for developing the new products (see, for instance, [1] and [2]). The scheduling of these attempts, hereafter referred to as alternatives, is crucial for increasing the likelihood of successfully developing a product, minimizing development time and obtaining revenues as early as possible. Consider, for instance, a software development firm that has the option to develop their web services using either a traditional Java SPRING framework or the pioneering Ruby-on-Rails framework. While both might achieve a similar functionality, the traditional Java SPRING framework will take longer to develop, but is more likely to handle the expected volume of users. A similar situation happens in the formulation, delivery and packaging development phase of the pharmaceutical drug-development process in which drug developers must devise a formulation that ensures the proper drug delivery parameters. It is critical to begin looking ahead to clinical trials at this phase of the drug development process. Drug formulation and delivery may be refined continuously until, and even after, the drug's final approval. Trials have different costs, durations and probability of success, and optimal scheduling of these trials saves a noticeable amount of money for the drug developer firm (see [3]).

In this paper, we focus on a single firm engaged in a single R&D or new product development (NPD) project. The project can be achieved by any one of several given alternatives. Each alternative is characterized by a cost, a duration and a probability of technical success (*PTS*). The successful completion of an alternative corresponds to the completion of the project and obtaining the project payoff. In other words, depending on the schedule and the realized successes of alternatives, some alternatives of the project will not be performed. Also, if in the time at which the success of an alternative is realized, there are some other alternatives in progress, they will be ignored. Since it is assumed that the cost of each alternative is incurred at the beginning of alternative while the project payoff will be obtained at the end of a successful alternative, there is the downside risk of disregarding some in progress alternatives. A serial schedule, in which alternatives are not attempted simultaneously, is conservative in terms of costs and minimizing the downside risk, but might result in the maximum project duration. On the other extreme, simultaneously developing all the potential alternative technologies, which could lead to the minimum project duration and an earlier launch date, carries a large downside risk and higher upfront costs (see, [4] and [5]). Our goal is to analyze such trade-offs and to solve the underlying optimization problem, which will be referred to as the

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Alternative-Technologies Project Scheduling Problem (ATPSP). The goal of the problem is to determine optimal timing of the alternatives such that the project's expected net present value (*eNPV*) is maximized. The most related problem to the ATPSP has been proposed by Creemers et al. [6], who develop a dynamic programming approach to solve a modular R&D project scheduling problem (RDPSP). Although modular RDPSP and ATPSP both try to use the advantages of alternative technologies, they differ in their objectives. Unlike ATPSP in which the objective function directly relates to the scheduling of alternatives, in modular RDPSP, the objective function relates to alternatives only indirectly, and mostly depends on the probability of success of each module. In other words, a solution is feasible in modular RDPSP if all of the modules succeed.

Planning and scheduling of NPD activities has been a challenging subject of research in recent years. Dahan [7] examines the trade-off between parallel and sequential scheduling in alternative prototype development. Granot and Zuckerman [8] examine the sequencing of R&D projects with success or failure in individual activities. Ding and Eliashberg [9] examine the 'pipeline problem': since NPD projects may fail in each stage, multiple projects are started simultaneously in order to increase the likelihood of having at least one successful product. Loch et al. [10] discuss the importance of exploratory learning and the value of partial information, thus highlighting the need for combined parallel and sequential planning. Also, Sobel et al. [11] consider the problem of scheduling projects with stochastic activity duration to maximize expected net present value.

De Reyck et al. [12] have presented a complete literature survey on project scheduling with activity failures. Following the classification introduced by De Reyck et al. [12], the project we consider in the ATPSP can be classified as a single-module project. Also, De Reyck and Leus [13] consider RDPSP in which project activities are interrelated by finish to start precedence relations. In their model, however, the project is successful only if all individual activities succeed. They develop a specialized branch-and-bound (B&B) algorithm for the RDPSP which includes two phases. In the first phase, a feasible extension for set of precedence relations is generated and in the second phase, each activity can be scheduled to end at the earliest of the start times of its successors in the extended set of precedence relations. Although there are similarities between ATPSP and RDPSP, the project success is achieved in the ATPSP if one alternative succeeds while this achievement is obtained in the RDPSP when no activity fails. Intuitively, we perceive that the number of situations in which the project is terminated in the ATPSP is much greater than in the RDPSP, and we conjecture that the ATPSP is harder to solve than the RDPSP. If we want to apply the B&B algorithm developed by De Reyck and Leus [13] for the RDPSP to the ATPSP, the second phase of this algorithm cannot be used because in the ATPSP, all intermediate alternative cash flows are not negative and, hence, in the optimal solution of this problem each alternative is not necessarily ended at the earliest of the start times of its successors. In other words, for the second phase, a new search methodology is required to find the optimal start time of each alternative.

Ranjbar [14] developed a two-phase solution procedure for the ATPSP which consists of a B&B algorithm that uses a recursive search procedure, developed by Vanhouck [15], as a subroutine to obtain an optimal solution. He presents each solution of the ATPSP as a sequence of start and finish events, and searches in the space of possible sequences for the optimal solution. The weakness point of his work was that the size of sequence is twice the size of alternatives; thus, his procedure is able to solve projects including at most eight alternatives in a reasonable time.

The contributions of this article are threefold: (1) we reformulate the ATPSP as a non-linear integer programming model; (2) we prove a property, referred to as the concurrency property, for the optimal solution of the ATPSP; and (3) we construct a new and improved B&B algorithm based on the concurrency property for the ATPSP.

The remainder of this paper is organized as follows. We illustrate an example in Section 2. The problem modeling and properties are presented in Section 3. In Section 4, we present the B&B algorithm. Computational results are discussed in Section 5. Finally, conclusions are given in Section 6.

2. An example

As an example, we consider a project with five alternative technologies for achieving a given breakthrough. The alternatives are represented by the nodes in Fig. 1, finish-to-start precedence constraints between the technologies are depicted by directed arcs.

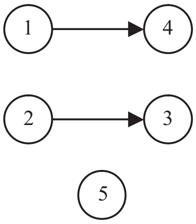

Fig. 1. Example project.

Table 1
Project data.

Alternative	Cost ($)	Duration (months)	*PTS*
1	− 51	8	0.73
2	− 31	6	0.62
3	− 87	3	0.91
4	− 28	7	0.57
5	− 80	4	0.86

Other project data are given in Table 1. In this example, we assume a discount rate of 5% per month and a project payoff, achieved in case of technological success, is $2770. Also, we assume the project deadline is 29 months.

For scheduling these alternatives, several choices can be made. If we try to obtain the project payoff as soon as possible, we can execute the alternatives according to the early-start schedule determined by the Critical Path Method (CPM). This schedule, depicted in Fig. 2(a), results in an *eNPV* of $2058.96. In this schedule, if alternative 5 is successful, the firm must still pay the expenses associated with alternatives 1 and 2, which are planned to start prior to completion of alternative 5, since the discovery of success or failure of the alternatives takes place only at the end of the alternative.

Another option is to schedule the alternatives carrying technical risk in series, thereby avoiding unnecessary costs when an alternative succeeds. One such series schedule is depicted in Fig. 2(b); this schedule results in an *eNPV* of $2083.61. Finally, a schedule allowing for a partial overlap of alternatives is shown in Fig. 2(c), yielding an *eNPV* of $2104.16, which can be shown to be optimal. Finding such a schedule is the objective of the algorithms that will be presented in this paper.

For each of the three foregoing schedules, the cumulative distribution function of the project's NPV is depicted in Fig. 3. For this project we observe that, while the downside is the most limited in the serial schedule, the CPM schedule has the lowest variance and the optimal schedule has the highest *eNPV*.