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Influence of learning in resource-constrained project scheduling

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ABSTRACT

Learning effects assume that the efficiency of a resource increases with the duration of a task. Although these effects are commonly used in machine scheduling environments, they are rarely used in a project scheduling setting. In this paper, the effect of learning in a project scheduling environment is studied and applied to the discrete time/resource trade-off scheduling problem (DTRTP), where each activity has a fixed work content for which a set of execution modes (duration/resource requirement pairs) can be defined. Computational results emphasize the significant impact of learning effects on the project schedule, measure the margin of error made by ignoring learning and show that timely incorporation of learning effects can lead to significant makespan improvements.

1. Introduction

Nowadays, organizations are making large investments in information technology (IT) in order to obtain a competitive advantage, to improve performance or to meet customer expectations (Kumar, 2002; Suwardy, Ratnatunga, Sohal, & Speight, 2003). These IT projects are, just like more industrial projects, a temporary endeavor undertaken to create a unique product or service (PMBOK, 2004). New technology and software projects, however, differ from other types of projects by their larger number of stakeholders (IT projects normally affect the whole company), their often changing requirements and higher risks (Milis, 2002; Plaza, 2008). Due to the special characteristics of IT projects, a large number of IT implementation projects run over time and budget. According to the Standish Group, only 16.2% of software projects can be categorized as successful, meaning they were completed on time, on budget and met user requirements (The Standish Group, 2014).

Numerous authors have identified a set of critical success factors for an IT project. Umble, Haft, and Umble (2003), Parr and Shanks (2000) and Slevin and Pinto (1986) emphasize the importance of a clear strategic plan and mission, the commitment by the top management, an excellent project management and a commitment to change within the organization. These authors also emphasize the importance of the implementation team, which starts with the careful selection of the team members (Baccarini, Salm, & Love, 2004) and is influenced by the knowledge transfer within the team (Robey, Roos, & Boudreau, 2002; Karlsen & Gottschalk, 2003). Moreover, Plaza (2008) pointed out that inaccurate predictions of team performance often lead to consequences of project creep and cost escalation.

Although it is accepted that the team's performance is affected by the team training and the team capabilities, little research has been conducted on the influence of team performance on the project duration.

Team training Since the team will use new technologies and methods of which they have little knowledge, early team training is an important success factor in IT projects (Plaza, Ngwenyama, & Rohlf, 2010). IT implementation teams need significant initial training followed by experimental learning (Robey et al., 2002). This team training will influence the initial team performance level. In case no initial training is provided, the team will start at a lower initial performance level, which will influence the activity and project duration.

Team capability Chatzoglou and Macaulay (1996) state that the capability of the project team is the single most important factor affecting the timely completion of software implementation projects. The capability encloses the competence and expertise of the team members, their motivation and the management style of the team managers (Chow & Cao, 2008) and determines the performance curve coefficient, which gives an indication of the team's learning rate.

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In recent papers, Plaza (2008) and Plaza et al. (2010) indicated the close relationship between team performance and learning. Wright (1936) was the first to denote this link by defining the concept of learning, which indicates the process of acquiring experience while performing similar activities leading to an improvement of the worker's performance. As a measurable result of learning, the time required to perform an activity decreases (Janiak & Rudek, 2007). Brazel (1972) and Sahal (1979) show that the same power function learning model as the repetition-based learning model noted by Wright (1936) can be used to indicate the learning which takes place over time. Hanakawa, Morisaki, and Matsumoto (1998) reveal that learning effects exist in software development settings and show that the productivity of a developer will increase if he/she stays longer on the task. In this paper, the level of team training and team capability are taken as input variables of the team learning function.

In the project scheduling literature, most models assume static and often homogeneous team performance (Heimerl & Kolisch, 2010). Moreover, most authors assume that project managers incorporate learning aspects during the planning process (Verzuh, 2008). Nevertheless, since it is accepted that the team training and capability have an influence on the team's performance, it is important to study their influence for the following reasons:

- A project manager not always defines the exact resource and duration requirements, but assigns a number of man days to each activity. This will have an influence on the team performance: smaller teams which have more time to execute an activity will have more time to learn compared to larger teams with less time.
- Project duration is often optimistically estimated with an input from the software vendor, who is often biased due to the gained competence from repeated implementation of the software in other firms (Plaza et al., 2010).

This research is of interest to project managers because (1) it analyzes the influence of the introduction of learning effects in project scheduling, (2) it determines the driving variables which can explain the difference between a schedule with and without learning effects and finally, and (3) it investigates the influence of learning effects on the accuracy of resource-constrained project schedules, in order to provide insights in the scheduling process with learning effects and to supply managerial understandings to optimize the decision process. Bochenski (1993) stated that project managers could obtain a competitive advantage by incorporating learning effects in order to obtain better deadlines and to use the available resources more efficiently.

The remainder of this paper is organized as follows. In the remainder of this section, a literature overview and the modeling aspects of learning effects applied to scheduling problems is given. The methodology used in this paper is explained in Section 2. In Section 3, the discrete time/resource trade-off problem is presented and the mathematical modeling of the learning effect in this scheduling problem is given. Section 4 discusses the solution approach while Section 5 gives an overview of the purpose and design of the computational experiment. The results for the computational experiments are shown in Section 6, while in Section 7, the conclusions of this research are formulated.

1.1. Learning in literature

Wright (1936) was the first to define the effect of learning. He described the link between working costs per unit and the production output in the aircraft industry and discovered that for every redoubling of the output, the unit processing time of an aircraft decreases by 20%. This empirical phenomenon, where the cumulative average worker hours will decline by a certain percentage of the previous cumulative average rate when the production quantity of a product doubles, was observed in various scientific areas since then. Various learning curves have been proposed since then. The three main curves are the log–lineair curve (Wright, 1936), the S-curve (Carr, 1946) and the exponential progress curve (Mazur & Hastie, 1978). For an overview of the available learning models the reader is referred to Yelle (1979) and Nembhard and Uzumeri (2000).

During decades, researchers were convinced that learning effects were the result of the repetitive execution of activities or tasks. However, younger learning literature distinghuishes two different groups of learning:

- *Autonomous learning* results from repeating similar operations, leading to a higher familiarization and routine (Biskup, 2008). The productivity of the workforce increases due to experience (earlier performance, mistakes, etc.) and these experiences grow by repeatedly execute specific activities or tasks. This type of learning is also referred to as *learning-by-doing* or the *Horndal-effect*. In this paper, we assume that this kind of learning occurs during project execution.
- *Induced learning* is the result of management investing in the know-how and the productivity of the human resources (Adler & Clark, 1991; Upton & Kim, 1998). Additional training, changes in the remuneration system and production environment, innovative education or incentive schemes are examples of management decisions which can influence the learning rate of the human resources. Important in this case is the determination of the optimal learning rate, since a reduction of the learning rate is usually related to higher costs.

Learning effects have been discussed in the scheduling literature from various angles. In the *staff scheduling* literature, several authors already modeled efficiency to cope with the effects of learning. Wu and Sun (2006) denoted that the efficiency of staff will improve by doing more. They developed a genetic algorithm to minimize the total outsourcing costs for a project with a fixed time horizon. Heimerl and Kolisch (2010) presented an optimization model to address the problem of assigning project work to multi-skilled internal and external human resources while considering learning, depreciation of knowledge and company skill level targets.

In *multi-project scheduling*, Shtub, LeBlanc, and Cai (1996) and Amor and Teplitz (1998) developed heuristic and meta-heuristic procedures for scheduling projects with a repetitive nature under learning effects. Ash and Smith-Daniels (1999) presented a heuristic for a multi-project scheduling problem where project preemption is allowed and learning, forgetting and relearning effects are introduced. They stated that, during the execution of an activity in development projects, people continuously learn and become more activity-efficient. They define learning as the increased productivity during the course of each project activity (*activity-specific learning*), a concept that will also be applied in this paper.

Plaza et al. (2010) presented a comparative analysis of learning curves and proposed how they can be used to help ERP implementation planning and management. They emphasize the impact of intensive in-house training on project planning and management.

The main focus of this paper is to investigate the influence of learning on the project duration. It is assumed that autonomous learning occurs during the course of each individual project activity. The learning curve as proposed by Wright (1936) is used as basis to model this process. Other learning models were also tested, but resulted in similar results. However, since it is not the