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Learning curve models and applications: Literature review and research directions

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ABSTRACT

Learning curves (LCs) are deemed effective tools for monitoring the performance of workers exposed to a new task. LCs provide a mathematical representation of the learning process that takes place as task repetition occurs. These curves were originally proposed by Wright in 1936 upon observing cost reduction due to repetitive procedures in production plants. Since then, LCs have been used to estimate the time required to complete production runs and the reduction in production costs as learning takes place, as well as to assign workers to tasks based on their performance profile. Further, effects of task interruption on workers' performance have also being modeled by modifications on the LCs. This wide variety of applications justifies the relevance of LCs in industrial applications. This paper presents the state of the art in the literature on learning and forgetting curves, describing the existing models, their limitations, and reported applications. Directions for future research on the subject are eventually proposed.

Relevance to industry: The Learning Curve (LC) models described here can be used in a wide variety of industrial applications where workers endeavor new tasks. LC modeling enables better assignment of tasks to workers and more efficient production planning, and reduces production costs.

1. Introduction

The way workers improve their performance as repetitions of a manual-based task take place has been studied in many industrial segments, such as electronic, automotive, construction, software, and chemical companies (Anderson, 1982; Nembhard and Osothsilp, 2002; Nembhard and Uzumeri, 2000a; Pananiswami and Bishop, 1991; Adler and Clark, 1991; Vits and Gelders, 2002; Hamade et al., 2007; Chen, 2009; Jarkas, 2010; Weber and Fayed, 2010). Several factors may impact the workers' learning process; namely: (*i*) structure of training programs (Terwiesch and Bohn, 2001; Vits and Gelders, 2002; Serel et al., 2003; Azizi et al., 2010); (*ii*) workers' motivations in performing the tasks (Kanfer, 1990; Eyring et al., 1993; Natter et al., 2001; Agrell et al., 2002); (*iii*) prior experience in the task (Nembhard and Uzumeri, 2000a, 2000b; Nembhard and Osothsilp, 2002); and (*iv*) task complexity (Pananiswami and Bishop, 1991; Nembhard and Osothsilp, 2002). Other studies have measured knowledge and dexterity retention after task interruption (Dar-El and Rubinovitz, 1991; Wickens et al., 1998; Nembhard and Uzumeri, 2000b; Jaber and Guiffrida, 2008). The way such factors impact workers' learning process can be analyzed by means of mathematical models named Learning Curves (LCs).

The LC has proven to be an efficient tool to monitor workers' performance in repetitive tasks, leading to reduced process loss due to workers' inability in the first production cycles (Argote, 1999; Dar-El, 2000; Salameh and Jaber, 2000; Jaber et al., 2008). LCs have been used to analyze and control productive operations (Chen et al., 2008; Jaber and Saadany, 2011; Janiak and Rudek, 2008; Lodree et al., 2009; Wahab and Jaber, 2010; Anzanello and Fogliatto, 2010), to allocate tasks to workers according to their learning profiles (Teplitz, 1991; Uzumeri and Nembhard, 1998; Nembhard and Uzumeri, 2000a; Anzanello and Fogliatto, 2007; Heimerl and Kolisch, 2010), to measure production costs as workers gain experience in a task (Wright, 1936; Teplitz, 1991; Sturm, 1999; Nadeau et al., 2010), and to estimate costs of consulting and technology implementation (Plaza and Rohlf, 2008; Plaza et al., 2010).

In view of its wide applicability in production systems and given the increasing number of publications on the subject, we present here a literature review on LCs covering the most relevant models and application scenarios. There are two main contributions in this paper. First, we discuss mathematical aspects of univariate and multivariate LCs, describing their applications, modifications to suit specific purposes, and limitations. Second, we propose directions for future research on LC that are aligned with current trends in production strategy such as Mass Customization.

This paper is organized as follows. Section 2 presents the main families of LC models and their mathematical aspects. Section 3 sets an agenda for future research on the subject. A conclusion is presented in Section 4.

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