PERGAMON

Omega 29 (2001) 491–499

omega
The International Journal
of Management Science

www.elsevier.com/locate/dsw

Learning curve analysis in total productive maintenance

F.-K. Wang*, W. Lee

Department of Business Administration, Chang Gung University, 259 Wen-Hwa 1st Road, Kwei-Shan, Taoyuan 333, Taiwan

Received 19 May 2000; accepted 6 June 2001

Abstract

The continuous improvement concepts such as total quality management, just-in-time and total productive maintenance have been widely recognized as a strategic weapon and successfully implemented in many organizations. In this paper, we focus on the application of total productive maintenance (TPM). A random effect non-linear regression model called the Time Constant Model was used to formulate a prediction model for the learning rate in terms of company size, sales, ISO 9000 certification and TPM award year. A two-stage analysis was employed to estimate the parameters. Using the approach of this study, one can determine the appropriate time for checking the performance of implementing total productive maintenance. By comparing the expected overall equipment effectiveness (OEE), one can improve the maintenance policy and monitor the progress of OEE. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Learning curve; Overall equipment effectiveness; Total productive maintenance

1. Introduction

Many systems in practice today do not perform as intended, nor are they cost effective in terms of their operation and support. Manufacturing systems, in particular, often operate at less than full capacity. Consequently, productivity is low and the cost of producing products is high. In dealing with the aspect of cost, experience has indicated that a large percentage of the total cost of doing business is due to maintenance-related activities in the factory (i.e., the costs associated with maintenance, labor and materials and the cost due to production losses). Further, these costs are likely to increase even more in the future with the added complexities of factory equipment through the introduction of new technologies, automation, the use of robots, and so on. In response to maintenance and support problems in the typical factory environment the Japanese in 1971, introduced the concept of total productive maintenance (TPM), an integrated life cycle approach to factory maintenance and support. Since then, TPM methods and techniques have been successfully implemented in Japan, and later on in some other advanced and advancing countries in the world. Inherent within the TPM concept are the aspects of enhancing the overall effectiveness of factory equipment, and providing an optimal group organizational approach in the accomplishment of system maintenance activities. Both the equipment and the organizational sides of the spectrum need to be addressed in fulfilling the objectives of TPM. It is believed that while many successes have been realized in structuring organizations to respond better to the maintenance challenge, very little progress has been made in relation to the prediction of total equipment utilization while implementing TPM. In this paper, we focus on the application of TPM. A random effect non-linear regression model called the Time Constant Model [1] was used to formulate a prediction model for the learning rate in terms of company size, sales, ISO 9000 certification and TPM award year. A two-stage analysis was employed to estimate the parameters. Using the approach of this study, one can determine the appropriate time for checking the performance of implementing total productive maintenance. By comparing the expected overall equipment effectiveness (OEE) one can improve the maintenance

* Corresponding author. Tel.: +886-3-328-3016; fax: +886-3-327-1304.
E-mail address: fukwun@mail.cgu.edu.tw (F.-K. Wang).

PII: S0305-0483(01)00039-1

policy and monitor the progress of OEE. The literature review on learning curves and TPM studies is presented in the following section. The learning curve analysis in TPM is discussed in Section 3, followed by some examples to demonstrate the application of the proposed methodology. The conclusions are made in the final section.

2. Literature review

Learning curves have been extensively studied, starting with Wright in 1936, and have been applied in practice [2]. It has been observed that every time the cumulative production volume doubles, the marginal cost diminishes by a fixed proportion (i.e., one minus the so-called learning rate). In that sense, the learning curve function is a power function with respect to the cumulative production volume. Learning rates are often similar to the same line of products [3]. However, Argote and Epple [4] report that organizations vary considerably in their learning rates for manufacturing the same products.

Muth [5] provides a survey of the theories that attempt to explain the learning curve phenomenon and propose a theory based on a random search within a fixed population of technological possibilities. Adler and Clark [6] propose a learning process model that relates the productivity improvement in an electric equipment company to first-order learning (cumulative output) and second-order learning (i.e., engineering changes and work force learning). Zangwill and Kantor [7] propose a model for continuous improvement activities and relate it to three forms of learning curves.

Few researchers have discussed the application of the learning curves in product quality and process improvement. Schneiderman [8] provides the times to halve the defect rates for many processes using a learning curve model that relates the logarithms of defect level to time. The paper reports the importance of identifying and setting targets for managing improvement activities. Comptom et al. [9] propose three learning models related to quality—the power form, the exponential form, and the linear form. In these, a measure of quality improvement (or quality index) is expressed as a function of cumulative volume.

For comprehensive surveys of the learning curve models, the reader is referred to Yelle [2], Hacket [10], Towill [11], and Badiru [12]. However, all papers mentioned in these studies address improvement measured by means of either productivity or product quality. In this paper, we address learning by means of overall equipment effectiveness (OEE).

Total productive maintenance, proposed by Seiichi Nakajima, has been widely applied for its benefits to the maintenance deliver system since 1971 [13]. The word “total” in total productive maintenance has three meanings that describe the principal features of TPM:

(1) Total effectiveness (including productivity, cost, quality delivery, safety, environment and health, morale).
(2) Total maintenance system (including maintenance prevention (MP), maintainability improvement (MI)).
(3) Total participation of all employees.

Thus, the goal of TPM is to increase the productivity of plant and equipment through company-led small group activities and autonomous maintenance by operators. To maximize output, the most efficient way is to eliminate causes, the so-called *six big losses* in TPM that reduce equipment effectiveness. (Six losses are: (1) reduced yield—from start up to stable production, (2) process defects, (3) reduced speed, (4) idling and minor stoppages, (5) set-up and adjustment, and (6) equipment failure.)

In the evaluation of a maintenance performance, OEE is used as a metric to evaluate the manufacturing capability. OEE is a function of equipment availability, performance efficiency, and quality. That is,

$$\text{OEE} = (\text{availability}) \times (\text{performance efficiency})$$
$$(\text{quality rate}),$$

where

$$\text{availability} = \frac{\text{loading time} - \text{downtime}}{\text{loading time}}$$

$$\begin{aligned}\text{performance efficiency}\\ &= \text{operating speed rate} \times \text{net operating rate}\\ &= \frac{\text{theoretical cycle time}}{\text{actual cycle time}}\\ &\quad \times \frac{\text{process amount} \times \text{actual cycle time}}{\text{operating time}}\\ &= \frac{\text{theoretical cycle time} \times \text{process amount}}{\text{operating time}}\end{aligned}$$

$$\text{quality rate} = \frac{\text{processed amount} - \text{defect amount}}{\text{processed amount}}.$$

An 85% OEE is considered as being world class and a benchmark to be established for a typical manufacturing capability. In practice, achieving an 85% OEE and obtaining a prize-winning award are objectives of firms when implementing TPM. Typically, it takes an average of three and a half years from introduction of TPM to achieve prize-winning results.

Several books and articles have presented TPM improvement activities in plants and, based on case studies, suggested the implementation procedures [14–19]. However, both Enkawa [20] and Miyake and Enkawa [21] develop in-depth systematized comparisons under the perspective of analyzing mutual complementary between total quality control (TQC) and TPM.

McKone et al. [22] propose a theoretical framework by testing how the contextual issues affect firms' maintenance systems when implementing TPM. Their studies show that the proposed three contexts—environmental context (country, industry), organizational context (equipment age, equipment type, company size, plant age, unionization),