ELSEVIER

European Journal of Operational Research 135 (2001) 128–141

EUROPEAN JOURNAL OF OPERATIONAL RESEARCH

www.elsevier.com/locate/dsw

Theory and Methodology

Optimal investment in setup reduction in manufacturing systems with WIP inventories

T.J. Nye [a,*], E.M. Jewkes [b], D.M. Dilts [c]

[a] *Mechanical Engineering Department, McMaster University, Hamilton, Ont., Canada L8S 4L7*
[b] *Management Sciences Department, University of Waterloo, Waterloo, Ont., Canada N2L 3G1*
[c] *School of Engineering and Owen Graduate School of Management, Vanderbilt University, Nashville, TN 37203, USA*

Received 13 July 1999; accepted 6 November 2000

Abstract

A number of models have been proposed to predict optimal setup times, or optimal investment in setup reduction, in manufacturing cells. These have been based on the economic order quantity (EOQ) or economic production quantity (EPQ) model formulation, and have a common limitation in that they neglect work-in-process (WIP) inventories, which can be substantial in manufacturing systems. In this paper a new model is developed that predicts optimal production batch sizes and investments in setup reduction. This model is based on queuing theory, which permits it to estimate WIP levels as a function of the decisions variables, batch size and setup time. Optimal values for batch size and setup time are found analytically, even though the total cost model was shown to be strictly non-convex.

Keywords: Inventory; Manufacturing; Queuing; Setup time reduction; Lot sizing

1. Introduction

Setup time reduction in manufacturing operations is widely recognised to provide significant benefits in areas such as cost, agility and quality. Many techniques are available to improve setup times, such as revising setup procedures, modifying tooling for standardised locating and clamping, or introducing robotic change-over equipment, to name a few. Each technique will provide a certain level of benefit, and have an associated cost. Given that the goal of the firm is to select the setup reduction techniques that will minimize their overall costs, this paper develops an analytic model that can be used to predict optimal investments in setup reduction, while taking into account WIP inventory costs.

* Corresponding author. Tel.: +1-905-525-9140; fax: +1-905-572-7944.
E-mail addresses: nyet@mcmaster.ca (T.J. Nye), emjewkes@uwaterloo.ca (E.M. Jewkes), david.dilts@owen.vanderbilt.edu (D.M. Dilts).

PII: S 0 3 7 7 - 2 2 1 7 (0 0) 0 0 3 0 8 - 8

Although arguments for setup time reduction have been made for some years now (e.g., Schonberger, 1982; Hall, 1983), the issue of justifying investments and optimally allocating finite resources has to a large extent been glossed over. For instance, one of the primary manuals on setup reduction techniques (Shingo, 1985) advocates reducing setup times to less than 10 minutes, without offering reasons for this particular target, nor mentioning what target is appropriate in the admittedly significant number of cases where 10 minute setups cannot be achieved. The philosophy that organizations should strive for zero setup times is laudable, but may not be a pragmatic objective in and of itself. For example, a manufacturer of N products may achieve zero setup times by providing N parallel production systems, each dedicated to one product. Clearly, N does not need to be very large before the costs of achieving zero setup times will far outstrip any potential economic advantages.

Some analytic models that deal with the problem of selecting appropriate levels of setup reduction investment are found in the literature. Probably the first is that due to Porteus (1985). This model extended the standard economic order quantity (EOQ) model to include the ordering cost (assumed to represent the setup cost in a manufacturing operation) as a decision variable in the model. By assuming a suitable functional relationship for setup time vs. cost, the optimal setup time and batch size that minimised total costs were determined. This model has been followed by a number of others incorporating various extensions. For example, Spence and Porteus (1987) found optimal setup reduction with a multi-product capacitated EOQ model, followed by similar models by Hwang et al. (1996), Moon (1994) and Banerjee et al. (1996). Dynamic lot sizing models with setup reduction have also been developed by Zangwill (1987), Hong et al. (1996), Mekler (1993) and Diaby (1995). A variant of the EOQ model, the economic production quantity (EPQ) model, was adapted by Billington (1987) to include setup reduction as a decision variable, with variations of the EPQ model by Cheng (1989), Kim et al. (1992), Kim and Arinze (1992), Trevino et al. (1993) and Sarker and Coates (1997).

A fundamental limitation to these EOQ-based models, however, is that while they take finished goods cycle-stock inventories into account, they do not consider the costs of work-in-process (WIP) inventories. This is a significant omission as, for instance, Boucher (1984) has pointed out "observation of large-scale discrete parts production facilities will show that the largest component of inventory cost is work-in-process inventory". Models which only capture finished goods inventory costs may not adequately represent manufacturing systems, and predictions made with such models may lead to sub-optimal or erroneous decisions. For instance, when using an EPQ-based model, Kim (1990, p. 85) found that the benefits of setup reduction decreased as the utilization of the manufacturing system increased. This finding runs counter to intuition, and can be explained by a property of the EPQ model: as system utilization increases, the EPQ model predicts that finished goods inventory will decrease, leading to less benefit from reducing setup time. WIP inventories, on the other hand, are known to increase as utilization increases (e.g., see Tijms, 1994). By not including WIP inventories, these existing models neglect one of the more significant cost justifications for setup reduction investment.

Karmarkar (1987) developed a model of a manufacturing operation that captures WIP costs. This model is based upon the M/M/1 queue, and treated production batch sizes as an independent variable. Analogous to the EOQ model, Karmarkar showed that smaller batches led to higher ordering (or setup) costs while larger batches led to higher WIP holding costs (determined from batch waiting times in the M/M/1 queue). An optimal batch size could be determined which minimised the sum of setup and inventory costs.

Hong (1995) used a deterministic model of the value of a product (based on a model by Groover, 1987) as it progressed through a manufacturing system to capture WIP costs. Both models assume that added value of a part increases linearly with its time in the system which is the sum of setup, operation and non-operation (i.e., waiting) times at each stage. Hong's model allowed WIP costs to be estimated, and minimization of total costs led to an expression for optimal lot size. Reduction of setup and non-operation times was shown to be important to reducing overall manufacturing lead times, but as the costs of bringing about reductions in setup and non-operation times were not considered, specific recommendations for reduction