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Lot sizing for an imperfect production process with quality corrective interruptions and improvements, and reduction in setups

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Abstract

The just-in-time (JIT) management philosophy advocates the elimination of waste or activities that add cost and not value to the product. Eliminating waste in the production process could be attained through smaller batch (lot) sizes and reduction of in-process inventory, where concepts such as setup reduction and increased quality are fundamental. In a JIT environment workers are authorized to stop production if a quality or a production problem arises, e.g., the production process going out-of-control. In such a case, the production process is interrupted for quality maintenance to bring the process in control again. This paper investigates the lot sizing problem for reduction in setups, with reworks, and interruptions to restore process quality. This paper assumes the rate of generating defects to benefit from any changes for eliminating the defects, and thus reduces with each quality restoration action. A mathematical model is developed and numerical examples are provided with results discussed.

Keywords: Lot sizing; Setup reduction; Quality improvement; Reworks

1. Introduction

The classical lot sizing problem, also known as the economic order/manufacture (EOQ/EMQ) quantity model, has captivated the attention of researchers since the earliest decades of the past century. The simplistic assumptions of the EOQ model that make its mathematics easy to use and understand is probably why the EOQ problem has been widely accepted and used by researchers and practitioners alike. Harris (1915) is assumed to be the first to provide a scientific approach to inventory management by developing the EOQ square root formulae. Since, there has been a plethora of work that extended upon the work of Harris with a reasonably good survey of these works provided in Silver, Pyke, and Peterson (1998). These extensions relaxed one or more assumptions inherent in the EOQ model to develop mathematical models that more

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closely conform to real-world inventory systems. Among these assumptions is that items produced and stocked are of perfect quality. This is an unrealistic assumption since the product quality is directly affected by the reliability of the production process (Cheng, 1991). Readers may refer to the work of Wright and Mehrez (1998) who provided a taxonomy of the research that includes the relationship between quality and inventory.

In spite of the emphasis in quality control, some manufacturing processes today are imperfect and result in defective items that require reworking (Buzacott, 1999). Electronics manufacturing (e.g., printed circuit boards assembly, semiconductor wafers fabrication, etc.) is an example of such imperfect processes (Agnihothri & Kenett, 1995; Gopalan & Kannan, 1995; Geren & Redford, 1999), and of batch (lot) manufacturing (Zargar, 1995). Besides electronics manufacturing, rework is an important issue in many process industries, such as the glass, steel, and pharmaceutical (Flapper, Fransoo, Broekmeulen, & Inderfurth, 2002), which are batch (lot) manufacturing too.

Reworking defective items requires additional effort that adds cost and not value to the product, which the just-in-time (JIT) philosophy considers as waste to be eliminated (e.g., Waters, 2003). The JIT advocates that inventory is a blanket that covers problems is production and quality. Reducing inventory uncovers these problems making it easier for management to solve. These problems could be deracinated through the implementation of continuous improvement programs. Ideas such as reduction of lot sizes and setups, shorter lead-times, zero defects, preventive maintenance, and flexible workforce are among many concepts inherent in continuous improvement. These concepts enticed researchers in inventory management to put the classical EOQ/EMQ model in context with JIT to better understand the latter (e.g., Cao & Schniederjans, 2004; Chyr, Lin, & Ho, 1990; Jones, 1991).

Porteus (1986) is among the earliest researchers who investigated the EOQ/EMQ model in conjunction with setup reduction and quality improvements. He showed that reducing the setup cost (time) and subsequently the lot size results in less reworks. The work of Porteus (1986) has been the cornerstone for many models. Some of these models are surveyed here. Chand (1989) studied the effect of learning in setups and process quality on the optimal lot sizes and the setup frequency. Khouja and Mehrez (1994) formulated an EMQ model with production rates as decision variables and assumed the percentage of good quality items in a lot decreases as the production rate increases resulting in more reworks. Urban (1998) investigated a production lot-size model that explicitly incorporates the effect of learning on the relationship (positive or negative) between the run length and defect rate. Khouja (1999) considered the economic lot scheduling problem with controllable production rates and imperfect quality. In a subsequent paper, Khouja (2000) extended the economic lot scheduling and delivery problem to the case of imperfect quality. Recently, Khouja (2003) formulated and solved two-stage supply chain inventory models in which the proportion of defective products increases with increased production lot sizes. Most recently, Freimer, Thomas, and Tyworth (2006) considered the EMQ model with defects produced according to some time-varying function.

A primary assumption to the work of Porteus (1986) is that a process could go out-of-control with a given probability each time an item is produced, where the process produces defective items until the entire lot is produced. After which the process is corrected and resumed in control at the beginning of the subsequent lot. Conversely, in a JIT manufacturing environment line workers have the authority to stop the line if a quality or a production problem arises (Inman & Brandon, 1992). This perhaps what enticed Khouja (2005) to reformulate the model of Porteus (1986) in which adjustment to the process can be made within a production cycle to restore it to an ‘‘in-control’’ state.

Prior to the work of Khouja (2005), Salameh and Jaber (1997) investigated the EOQ/EMQ model with regular maintenance interruptions as preventive action. They have not attributed this interruption to restore the quality of the production process, but to avoid a major machine breakdown. Independently, the works of Khouja (2005) and Salameh and Jaber (1997) assumed inventory to behave in exactly the same manner, and that the setup cost function, $S(n) = S + ns$, consist of a fixed component, S, and a variable component, s, where n is the number of minor setups within a cycle. The cost of a major setup, S, involves all tasks required for preparing and adjusting the production process, while s is the cost of a minor setup which involves only the tasks required to restore the process to an ‘‘in-control’’ state.

This paper integrates the works of Chand (1989) and that of Khouja (2005) by assuming that the major setup cost reduces with every setup (e.g., because of learning effects), and that the rate of generating defects