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Improved quality, setup cost reduction, and variable backorder costs in an imperfect production process

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ABSTRACT

This paper illustrates the relationship between quality improvement, reorder point, and lead time, as affected by backorder rate, in an imperfect production process. To reduce the total system cost by optimizing the setup cost, lot size, lead time, reorder point, and process quality parameter simultaneously, we first consider that the lead time demand follows a normal distribution, then we apply the distribution free approach for the lead time demand. We prove two lemmas which are used to find optimal solutions for the basic and distribution free models. We compare our models with the existing models using numerical examples and show that significant savings over the existing models can be achieved.

1. Introduction

Since the invention of the economic order quantity by Harris (1913), many continuous applications of it have been seen in different sectors of everyday life. In Harris's model, most of the values are taken as constants. Silver (1992) suggested '*changing the givens*' concept such that constant terms are regarded as decision variables, and many researchers have used it to obtain new models that incorporate improvement efforts. As a practical matter, not all factors, such as lot size, backorder rate, lead time, and quality control parameter remain constant. Therefore, an enormous amount of research came from different sectors. The researchers faced problems in discussing their models because of the difficult and time-consuming process in determining the lead time demand distribution. Scarf (1958) found a min–max solution of the newsvendor problem in which only the mean and the standard deviation of the lead time demand distribution are assumed to be known. Though beautifully explained, the model is difficult to understand and efficiently implement.

Gallego and Moon (1993) made Scarf's (1958) ordering rule very easy. Moon and Gallego (1994) discussed different ways of applying the distribution free procedure for some inventory models. Ben-Daya and Raouf (1994) developed an inventory model in which the lead time is a decision variable. Moon and Choi (1995) extended the distribution free newsvendor problem to allow customer balking. Ouyang et al. (1996) extended the model of Ben-Daya and Raouf (1994) by adding the lead time demand cost. They considered the total amount of the lead time demand as a mixture of backorders and lost sales during the stockout period. Ouyang and Wu (1997) discussed an inventory model with a service level constraint in which lead time is variable and applied the distribution free approach.

By correcting the model of Ouyang et al. (1996) and Moon and Choi (1998) developed a complete solution algorithm for the model in which the lead time is a decision variable. Ouyang and Wu (1998) discovered both the optimal order quantity and the lead time by taking them as decision variables in a distribution free procedure, thus extending the concept of Ben-Daya and Raouf (1994) and Ouyang et al. (1996). Hariga and Ben-Daya (1999) discussed stochastic inventory models with a deterministic lead time and optimal ordering decision. Ouyang et al. (2002) extended the model of Moon and Choi (1998) by considering quality improvement and setup cost reduction. To reduce total system expense, Chuang et al. (2004) investigated the periodic review inventory model with a mixture of backorders and lost sales by simultaneously controlling the lead time and the setup cost.

Alfares and Elmorra (2005) discussed the extension of the distribution free newsvendor problem with shortages. This model determines an optimal order quantity and a lower bound on the profit under the worst possible distribution of the lead time demand in single product, fixed ordering cost, random yield, and resource-constrained multi-product cases. Chu et al. (2005) corrected the solution algorithm of Ouyang and Wu (1997) by developing lemmas to reveal the parameter's effects and presenting two complete procedures to determine the optimal solution. Wu et al. (2007) discussed a computational algorithmic procedure for the optimal inventory policy involving a negative exponential

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crashing cost and lead time demand. Lee and Hsu (2011) derived the effect of advertising costs on the distribution free newsvendor problem. Liao et al. (2011) developed a distribution free newsvendor model with balking and lost sales penalty. Kono (2012) discussed a safe zone analysis for multiple investment alternatives on the total and unit cost domains. Nagasawa et al. (2012) developed the selection of ordering policy and items classification based on the canonical correlation and cluster analysis. Glock (2012) discussed a lead time reduction strategy in an integrated inventory model with lot size-dependent lead times and stochastic demand. Yoo et al. (2012) developed an optimal lot sizing model for an imperfect production and inspection system with customer return and defective disposal. Pal et al. (2013) studied a distribution free newsvendor problem in which the holding cost function depends on order quantity and the inventory level. Cobb (2013) explained a mixture distribution procedure for the lead time demand in a continuous review inventory model.

Most inventory models considered either constant backorder rate or price-dependent backorder rate. However, it is much more realistic to consider backorder rate as either planned or variable. In this direction, Ouyang and Chuang (2001) extended Ouyang et al.'s (1996) model to the model with variable backorder rate. See Table 1 for a comparison of our study with others.

Pan et al. (2004) and Pan and Hsiao (2005) discussed two inventory models based on price-dependent backorder rate. Lee (2005) considered the mixture of distributions model with controllable backorder rate and variable lead time. Lin (2008) developed an inventory model by simultaneously optimizing the order quantity, reorder point, backorder price discount, and lead time. Cárdenas-Barrón (2009) presented an inventory model with rework process at a single-stage production system with planned backorders and obtained a closed-form optimal solution. Chung and Cárdenas-Barrón (2012) developed a complete solution procedure for the economic order quantity and economic production quantity inventory models with linear and fixed backorder costs. Ouyang and Chang (2013) developed a mathematical model to find the optimal production policy for an EPQ inventory system with imperfect production processes under permissible delay in payments and complete backorder rate.

In our proposed model, we extend the study of Ouyang et al. (2002) by adding a variable backorder rate. We use the same assumptions as Ouyang et al. (2002), except for backorder rate, which may not always be constant as they presumed in their study. We consider backorder rate as a function of lead time such that increased shortage values indicate increased loss as customers refuse to wait for delivery. Hence, if the backorder rate is low, the

Table 1
Comparison between the contributions of different authors.

Author (s)	Distribution free approach	Variable lead time	Order quantity	Setup cost reduction	Quality improvement	Variable back order cost	Fixed back order cost	Variable reorder point
Harris (1913)			√					
Scarf (1958)	√		√					
Porteus (1986)			√	√	√			
Gallego and Moon (1993)	√		√					
Moon and Gallego (1994)	√		√				√	√
Ben-Daya and Raouf (1994)		√	√					
Moon and Choi (1995)	√		√					√
Ouyang et al. (1996)		√	√				√	
Ouyang and Wu (1997)	√	√	√				√	
Ouyang and Wu (1998)	√	√	√				√	√
Moon and Choi (1998)	√	√	√				√	√
Hariga and Ben-Daya (1999)	√	√	√				√	√
Ouyang and Chuang (2001)	√	√	√			√		
Ouyang et al. (2002)	√	√	√	√	√		√	√
Chuang et al. (2004)	√	√					√	
Lee et al. (2004)	√	√	√				√	√
Pan et al. (2004)	√	√	√			√[1]		√
Pan and Hsiao (2005)	√	√	√			√[1]		
Chu et al. (2005)	√	√	√				√	
Lee (2005)	√	√	√			√		
Alfares and Elmorra (2005)	√		√				√	
Wu et al. (2007)	√	√	√			√	√	
Lin (2008)	√	√	√				√[1]	√
Cárdenas-Barrón (2009)						√		
Liao et al. (2011)	√		√					
Lee and Hsu (2011)	√		√[2]				√	
Glock (2012)		√	√				√	√
Kono (2012)				√				
Nagasawa et al. (2012)				√				
Chung and Cárdenas-Barrón (2012)						√		
Yoo et al. (2012)			√		√			
Cobb (2013)	√	√						
Ouyang and Chang (2013)			√			√		
Pal et al. (2013)	√		√					
This model	√	√	√	√	√	√		√

√[1] indicates the backorder with price discount offer and √[2] indicates the model with the advertising policy.

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