Omega 42 (2014) 16–24

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

An integrated supply chain model with errors in quality inspection and learning in production

Mehmood Khan [a,*], Mohamad Y. Jaber [b], Abdul-Rahim Ahmad [c]

[a] College of Business Administration, Abu Dhabi University, P.O. Box 59911, Abu Dhabi, United Arab Emirates
[b] Department of Mechanical & Industrial Engineering, Ryerson University, Toronto, ON M5B 2K3, Canada
[c] Rowe School of Business, Dalhousie University, Halifax, NS B3H 4R2, Canada

ARTICLE INFO

Article history:
Received 17 July 2011
Accepted 5 February 2013
Processed by B. Lev
Available online 16 February 2013

Keywords:
Lotsizing
EOQ/EPQ
Supply chain coordination
Imperfect quality
Learning curve
Integrated modeling of supply chains

ABSTRACT

It is imperative for contemporary businesses to proactively search for ways of continuously improving the performance of their supply chains. Supply chain coordination and integrated decision making across the supply chain among various supply chain partners are frequently employed towards this end. Such supply chain coordination strategies include the use of common cycle time, quantity discounts, optimal lot sizing, quality improvements and inspections, etc. An important issue lacking in the supply chain literature relates to the incorporation of such quintessential and omnipresent human factors as errors in quality inspections and production improvements due to learning. This paper provides a simple but integrated mathematical model for determining an optimal vendor–buyer inventory policy by accounting for quality inspection errors at the buyer's end and learning in production at the vendor's end. The objective is to minimize the joint annual cost incurred in the supply chain. A numerical example is presented to illustrate the application and the substance of the proposed model. We discuss how such integrated models can be used for justifying investments in such strategic and operational areas as relationship management, product design, process design, and personnel training. We also provide some very interesting and challenging future research directions.

1. Introduction

In contemporary competitive business environment, it is imperative for businesses to continuously work on improving the performance of their supply chains. Consequently, integrated supply chain decisions and coordination across supply chains are frequently sought for improving performance of supply chains [25]. Indeed, rapid advancements in information and communication technologies have made integrated supply chain planning and coordination much more feasible [42,45]. In this regard, operations management practices and mathematical models provide a sound framework for effective and integrative decision making across supply chains [2,42]. The employment of the economic order/production quantity (EOQ/EPQ) models is quite common not only in the literature but also in the practice concerning inventory and lot sizing [2,44]. The original EOQ model, attributed to Harris [19], has been extended by incorporating a variety of real world situations, such as backordering, quantity discounts, multiplicity of stages, etc. [2]. Still such EOQ/EPQ models only provide a trade-off between holding and ordering costs of the buyer. Consequently, the traditional EOQ/EPQ model has several weaknesses. For example, the traditional EOQ/EPQ models assume perfect quality of the product, whereas imperfect product quality is a more likely and logical scenario. These unrealistic assumptions paved the path for many researchers to start incorporating quality in lot sizing decisions. Some representative examples of such literature in the single-stage contexts include Porteus [37], Rosenblatt and Lee [39], and Silver [43]. In addition, some seminal research has been done in multi-stage lot sizing decisions for imperfect production processes with imperfect production quality and imperfect quality screening by Ahmad [2], Ben-Daya and Rahim [5], Ben-Daya et al. [6] and Ben-Daya and Rahim [7]. These more realistic lot sizing models incorporate the idea of quality inspection and screening as well as process maintenance, disruptions, and restorations etc. [2,5,6,7]. Some other supply chain models link quality to lean manufacturing and warranty periods, such as Chung and Wee [10] and Wee and Wu [48].

Nevertheless, most of the advanced EOQ/EPQ model models largely ignore the role of human factors like inspection errors, fatigue and learning. Notably, such factors have not been incorporated in lot sizing models within the context of supply chain management. One likely reason for such dearth of research in incorporating inspection errors and learning in supply chain

* Corresponding author. Tel.: +971 553542147.
E-mail address: mehmood.khan@adu.ac.ae (M. Khan).

0305-0483/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.omega.2013.02.002

performance decisions is the complexity and uncertainty arising from inter-stage interactions. Nevertheless, these factors can play a vital role in measuring the performance of a supply chain. Consequently, there is a pressing need for expanding the scope of current literature in supply chain management by developing models that incorporate such critical factors as errors in quality inspections and learning in production into lot sizing and supply chain performance related decisions [7]. This paper provides a simple but effective mathematical model to determine an optimal vendor–buyer inventory policy for a single product. It takes into account quality inspection errors at the buyer's end and learning in production at manufacturer's end with an objective to minimize the joint annual cost incurred by the supply chain. Such data-driven analytical models can provide critical decision support to supply chain modelers and managers [42,45]. Indeed, an increasing number of researchers and practitioners are actively seeking analytical tools for effective and integrated decision support in supply chain management [2,42]. It should be emphasized here that Type I and Type II errors are attributed to false decisions made while screening an object. Type I error calls for a false acceptance of a defective item. In other words, the inspector rejects the null hypothesis H_0 in favor of the alternate hypothesis H_1 where H_0 is true. On the other hand, Type II error refers to a false rejection of a non-defective item. In this case, the inspector fails to reject the null hypothesis H_0, where H_0 is false [35]. The probabilities of these errors depend on the parameters of a process and are usually selected based on the history of an inspector [12].

The rest of the paper is organized as follows. Section 2 provides the survey of literature. Section 3 details the development of the mathematical model. Section 4 provides a numerical example to illustrate the applicability and efficacy of the model presented, and Section 5 concludes the paper with some interesting and challenging research directions.

2. Literature Survey

Quality inspection errors is an important aspect that demands due consideration in the inventory and supply chain management related literature. Bennett et al. [8] investigated the effects of inspection errors on a cost-based single sampling plan. Ahmad [2] and Ben-Daya and Rahim [7] incorporated inspection errors in integrated production, quality, and maintenance decisions in two-stage, as well as in multi-stage, imperfect production-inventory environments. Raouf et al. [38] developed a model for determining the optimal number of repeat inspections for multicharacteristic components in the presence of both Type I and Type II errors in the quality inspection process. Duffuaa and Khan [12] extended the model given in Raouf et al. [38] by adding the classifications like rework and scrap for imperfect items rather than naively classifying them only as defective and non-defective.

Learning is another essential human factor largely missing from the literature pertaining to inventory and supply chain management [28]. The seminal Learning Curve Theory (LCT) is based on the idea of reduction in the amount of time required to complete a specific recurring task due to experience [20,27]. Indeed, some researchers have incorporated the learning aspect in determining production lot sizes. Wortham and Mayyasi [50] proposed one of the first inventory models that studied the impact of learning on economic order quantities. Adler and Nanda [1] developed two models of optimal lot size with learning. The first one was restricted to the equal lot sizes while the second one was restricted to equal production intervals. Salameh et al. [40] investigated the effect of learning in a finite production process. Jaber and Bonney [23] developed inventory models for finite and infinite planning horizons where both learning and forgetting affect an optimal lot size. Jaber and Bonney [24] presented a review of the literature on EOQ/EPQ models that incorporates learning in production and set up of a process.

Salameh and Jaber [41] provided a new direction to the literature on inventory management. They presented a simple EOQ model for imperfect items. This paper has been extended a number of times recently. Few of these extensions are: Goyal and Cárdenas-Barrón [17], Goyal et al. [18], Wang [46], Papachristos and Konstantaras [36], Wee et al. [47], Eroglu and Ozdemir [14], Konstantaras et al. [33], Maddah and Jaber [34] and Khan et al. [29,30,31]. Hsu [21] corrected a few typos in Khan et al. [30]. A review of the models extending the work of Salameh and Jaber [41] can be found in Khan et al. [32].

Banerjee [4] was one of the first models that discussed the coordination between a vendor and a purchaser, where a joint economic lot size model for a purchaser is developed for a vendor that produces on a lot-for-lot basis. Such models were extended to include integrated production, quality inspections, and maintenance decisions by Ahmad [2], Ben-Daya and Rahim [5], Ben-Daya et al. [6], Ben-Daya and Rahim [7]. However, such crucial human factors as learning were not addressed in those extensions. Goyal [16] suggested a more general joint economic lot size model by relaxing the lot-for-lot assumption in Banerjee [4]. Huang [22] extended Salameh and Jaber [41] model for a two level supply chain. They adopted the equal shipment size policy in the integrated vendor–buyer inventory model with defective items. It can be said that integrated inventory management has recently received a great deal of attention. Readers may refer to Jaber and Zolfaghari [26] and Glock [15] for reviews.

This paper extends the model of Huang [22] for a two level supply chain with a realistic approach of errors in screening [38] and learning in production [23]. The rest of the paper is arranged as follows: in Section 3, a list of the notations and the description, formulation of the models are given. Section 4 presents numerical examples for the base model and the extensions, and Section 5 presents conclusions, limitations and some suggestions for future research.

3. Model description

Here, an equal lot size policy is adopted for a two-level vendor–buyer supply chain similar to Huang [22]. The vendor (manufacturer) follows an EPQ policy to manufacture a single product. The coordination mechanism is such that the vendor receives the buyer's demand and produces the single product; the vendor replenishes the order in a number of equal-sized shipments. We assume that the vendor experiences learning in the production process while some of the units are defective. The buyer institutes an inspection process as suggested by Salameh and Jaber [41] and the inspection process is prone to both Type I and Type II errors. The coordination between vendor and buyer is described with fixed and variable transportation cost. An optimal lot size and the annual cost are determined for the two level supply chains. The model is then extended to include Type I and Type II errors in the buyer's screening process. In the second extension, the vendor's production process is assumed to follow the Wright [51] learning curve, thus affecting the production time.

The costs considered in the model include ordering/setup cost, screening cost, the inventory carrying cost, shipment cost and the production cost. The buyer bears the fixed and the variable costs of a shipment to the buyer. An optimal production quantity and the number of shipments per cycle that minimizes the total annual cost of the supply chain is sought.