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Optimal replenishment policies for the case of a demand function with product-life-cycle shape in a finite planning horizon

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Abstract

In this paper, we explore the demand function follows the product-life-cycle shape for the decision maker to determine the optimal number of inventory replenishments and the corresponding optimal inventory replenishment time points in the finite planning horizon. The objective function of the total relevant costs considered in our model is mathematically formulated as a mixed-integer nonlinear programming problem. A complete search procedure is provided to find the optimal solution by employing the properties derived in this paper and the Nelder–Mead algorithm. Also, based on the search procedure developed in this paper, a decision support system is implemented on a personal computer to solve the proposed problem.
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Keywords: Inventory replenishment; Product life cycle; Nelder–Mead algorithm

1. Introduction

The objective of this paper is to explore the demand function follows the product-life-cycle shape for the decision maker to determine the optimal number of inventory replenishments and the corresponding optimal inventory replenishment time points in the finite planning horizon so that the total relevant costs is minimized. By employing the properties derived in this paper and the Nelder–Mead algorithm, a complete search procedure is provided to find the optimal solution. Moreover, based on the search procedure developed in this paper, a decision support system is implemented on a personal computer to solve the proposed problem.

One of the underlying assumptions for the classical economic order quantity (EOQ)/economic manufacturing quantity (EMQ) model is that the planning horizon is assumed to be infinity. Schwarz (1972) relaxed the assumption of the infinite planning horizon and presented a production inventory model to determine the optimal policies of the economic manufacturing quantity problem under the condition that the planning horizon is finite. In contrast to the constant demand considered in Schwarz (1972), Donaldson (1977) examined the case of a linear trend in demand and provided a computationally simple procedure to determine the optimal inventory replenishment time points in a finite planning horizon. After Donaldson (1977), numerous research works have been carried out by incorporating time-varying demand into inventory models under a variety of circumstances. Silver (1979) considered an inventory model with a linear trend in demand without shortage and derived an approximate solution procedure for the general case of a deterministic, time-varying demand pattern. Henery (1979) extended Donaldson's model (1977) to a general class of increasing demands for the inventory replenishment problem. Ritchie (1984) derived a simple optimal policy for the case of linear increasing demand which is analogous to the EOQ for constant demand. Amrani and Rand (1990) presented an eclectic heuristics

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involving in solving a cubic equation for the case of linear increasing demand to determine the replenishment problem chronologically. Yang and Rand (1993) described an analytic algorithm so that a near-optimal solution can be obtained by varying the parameter within a certain range. Teng (1994) proposed a hybrid heuristic method to determine the replenishment policies in the case of deterministic linear increasing demand. Goyal (1994) suggested a procedure involved in solving a cubic equation and $(n-1)$ quadratic equations to determine replenishment intervals for an n replenishments policy. Teng (1996) extended Teng (1994) to the case with allowable shortages and proposed a simple and efficient method in recursive fashion to solve the replenishment problem. We note that most of the above paper focused on the replenishment problem for the case of linear "increasing" demand. However, the literature concerning replenishment problem for the case of linear "decreasing" demand were also well documented.

Brosseau (1982) showed that the analytical solution for the case of linear decreasing demand can be conveniently analyzed and presented in tabular form by using a single parameter. Hariga (1995) conducted an empirical comparison to assess the cost and computation time performances of several heuristic procedures in the literature for the inventory replenishment problem with a linear increasing/decreasing demand. Lo, Tsai, and Li (2002) proposed a "two-equation model" to solve the replenishment problem for linear increasing and decreasing demand. Zhao, Yang, and Rand (2001) focuses on linear decreasing demand and proposed a new eclectic heuristic based on the roots of a cubic equation to determine the replenishment policy in a finite planning horizon. Goyal and Giri (2003) presented a backward searching rule for determining replenishment intervals of an inventory item with linear decreasing demand.

So far, we have examined the literature dealing with linear increasing and/or decreasing trend in demand for the replenishment problem in the finite planning horizon. In contrast to the case of linear trend demand, there have been several researchers who ever made contribution to the case of non-linear increasing demand for the replenishment problem. Yang, Zhao, and Rand (1999) developed an analytic algorithm to compare several heuristics by changing the parameter vector for the case of non-linear increasing demand. Wang (2002) proposed a consecutive improvement approach to solve the replenishment problem so that the inventory depletes to zero at the end of the planning horizon. Yang, Teng, and Chern (2002) developed a simple forward recursive algorithm to determine the optimal replenishment time points and proposed an intuitively accurate estimate for the number of replenishments to solve the inventory lot-size models with power-form demand. Roger (1996) investigated the replenishment policies for the life cycle of a product which has a continuous, time-varying deterministic demand pattern. The solving procedure in Roger (1996) is that the demand of life cycle is classified into several segments and solves the replenishment problem within each segment without considering the product life cycle as a whole.

In this paper, we explore the demand function follows the product-life-cycle shape for the decision maker to determine the optimal number of inventory replenishments and the corresponding optimal inventory replenishment time points in the finite planning horizon. The objective function of the total relevant costs considered in our model is mathematically formulated as a mixed-integer nonlinear programming problem. By employing the properties derived in this paper and the Nelder–Mead algorithm, a complete search procedure is provided to find the optimal solution. The remainder of this paper is organized follows. In Section 2, basic assumptions, model environments and mathematical notations are presented. In Section 3, we formulate the proposed problem as a cost minimization problem where the number of replenishments in the planning horizon and the corresponding replenishment time points are the decision variables. Following the mathematical formulation, in Section 4, a complete search procedure is provided to find the optimal solution by employing the Nelder–Mead algorithm. Also, based on the search procedure developed in Section 4, we implement a decision support system on a personal computer to solve the proposed problem in Section 5. Finally, the concluding remarks are made in Section 6.

2. Assumptions and notations

2.1. The assumptions about demand function

A key feature differentiates our paper from the previous works is that the demand function follows the shape of a product-life-cycle. Specifically, we assume that the demand function is a revised version from Beta distribution function. Namely,

$$f(t) = \frac{Q}{B(\alpha,\beta)} t^{\alpha-1}(H-t)^{\beta-1} \tag{1}$$

$$B(\alpha,\beta) = \int_0^H t^{\alpha-1}(H-t)^{\beta-1}\,\mathrm{d}t \tag{2}$$

where H is the planning horizon under consideration, Q is the cumulative quantity of the demand in the planning horizon and α, β are the constant parameters for the revised Beta distribution function. Different values of α and β will have different shapes of the demand function. In Fig. 1, we show three different sets of parameters for α and β to graphically depict the demand function. If $\alpha = 1$ and $\beta = 2$, the demand is expressed as a linear decreasing function. On the other hand, if $\alpha = 2$ and $\beta = 1$, the demand is expressed as a linear increasing function. If $\alpha = 6$ and $\beta = 3$, the demand function forms up like a product-life-cycle shape.

The demand with a product-life-cycle shape can be classified into four stages. At the beginning of the planning horizon (first stage), the demand increases very slowly. As time goes on, the demand increases very rapidly (second stage) and eventually reaches a peak (third stage). At the

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