Available online at www.sciencedirect.com
ScienceDirect
Computers & Industrial Engineering 52 (2007) 78–88
computers & industrial engineering
www.elsevier.com/locate/dsw

Lot sizing with permissible delay in payments and entropy cost

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Received 11 March 2006; accepted 27 October 2006
Available online 11 December 2006

Abstract

Although the lot size problem (i.e., the economic order quantity model) has been widely accepted and used by researchers and practitioners, it has also been criticized by others on the grounds that not accounting for some of the hidden costs in inventory systems often lead to poor results. This paper postulates that estimating these hidden costs may be attained by applying the first and second laws of thermodynamics to reduce system entropy (or disorder) at a cost. The applicability of this concept is demonstrated for the economic lot size problem with permissible delay in payments. Mathematical models are developed with numerical examples provided and results discussed.

Keywords: Lot sizing; Thermodynamics; Entropy cost; Price dependent demand; Economic order quantity; Permissible delay in payments

1. Introduction

The economic order quantity (EOQ) model, also known as the lot (batch) size problem, is the oldest scientific approach, and perhaps the simplest, to analyze inventory systems. The popularity of the EOQ model may have been attributed to the ease of manipulation and calculation (Woolsey, 1990). Since its development, there has been a plethora of work that extended the EOQ model in many directions with a good survey of these extensions provided in Silver, Pyke, and Peterson (1998).

Among these extensions is the investigation of the lot sizing problem with supplier trade credit incentives. The rationale for such a business practice by many suppliers is to promote commodities and gain larger market shares by offering credit terms to their customers-the retailers. The EOQ model under permissible delay in payments is among the extensions found in the literature. The earliest reported works are those of Haley and Higgins (1973), Kingsman (1983), Chapman, Ward, Cooper, and Page (1984), and Goyal (1985). Since, this research topic has been attracting the attention of researchers. Recent works, but not limited to, are those of Jamal, Sarker, and Wang (2000), Teng (2002), Salameh, Abboud, El-Kassar, and Ghattas (2003), and Chandrashekar and Gopalakrishnan (2005).

Although the EOQ model has been widely accepted and used by researchers and practitioners (Osteryoung, Nosari, McCarty, & Reinhart, 1986), it has also been criticized by others. Selen and Wood (1987) cautioned

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doi:10.1016/j.cie.2006.10.004

that substantial miscalculations or misinterpretations during parameter input determination often lead to poor results. Woolsey (1990) corroborated the conclusions of Osteryoung et al. (1986) that the assumptions necessary to justify the use of the EOQ model are never met. Jones (1991) cautioned that firms who fail to identify relevant costs in a system may result in over-estimating their lot sizes. Unfortunately, the usual cost parameters used in the EOQ model, particularly ordering cost, holding cost and shortage cost are difficult to estimate and so the results obtained may be misleading. For example, the holding cost is an aggregated cost that may include all (or some) of the following: cost of money tied up which is either borrowed (in which interest is paid) or could be put to other use (in which case there are opportunity costs), storage cost (supplying a warehouse, rent rates, heat, light, etc.), loss (due to damage, pilferage, and obsolescence), handling (including all movement, special packaging, refrigeration, putting on pallets, etc.), administration (stock checks, computer updates, etc.), insurance, and taxes (Waters, 2003). Some of these costs are difficult to estimate where other costs are hidden (Callioni, de Montgros, Slagmulder, Van Wassenhove, & Wright, 2005). In addition to these reported costs, there are hidden costs associated with inventory systems that are not usually accounted for (Pendlebury & Platford, 1988; Ullmann, 1982; Gooley, 1995; Crusoe, Schmelzle, & Buttross, 1999; Fisher & Siburg, 2003).

This paper presents an analogy between the behavior of production systems and the behavior of physical systems. Such a parallel suggests that improvements to management systems may be achievable by applying the first and second laws of thermodynamics to reduce system entropy (or disorder). This paper postulates the concept of entropy cost to estimate some of the difficult-to-estimate or hidden costs outlined above. Few researchers in the discipline of industrial engineering have applied classical thermodynamics reasoning to analyzing management systems. For example, the thermodynamic entropy concept has been applied to analyzing decision trees (Drechsler, 1968), manpower systems (Tyler, 1989), logistics management (Whewell, 1997), business process management (Chen, 1999), product life cycle (Tseng, 2004), inventory management (Jaber, Nuwayhid, & Rosen, 2004, 2006), price-quality relationship (Nuwayhid, Jaber, Rosen, & Sassine, 2006), and coordinating orders in a supply chain (Jaber, et al., 2006).

This paper incorporates the concept of entropy cost developed in Jaber et al. (2004) into the EOQ problem with permissible delay in payments, i.e., into the model of Goyal (1985). The remainder of this paper is organized as follows. In the next section, Section 2, a brief introduction to the first and second laws of thermodynamics is presented. Section 3 is for mathematical modeling of the inventory model of interest. Section 4 produces some numerical results that illustrate the behavior of the mathematical model. Section 5 provides further discussion of results. Finally, Section 6 presents a summary, conclusions and recommendations for future research.

2. The laws of thermodynamics and the concept of entropy

Thermodynamics is the physics of energy and work of a system, and the laws that govern the conversion of energy from one form to another. A basic assumption of thermodynamics is that the universe is divided into a system and its surrounding. A physical thermodynamic system is defined by its properties, which are temperature, volume, pressure and chemical composition. A system is in equilibrium when these variables have the same values at any time. There are two laws (the first and the second) of thermodynamics that are of interest here. Readers may refer to Cengel and Boles (2002) as a recommended textbook on thermodynamics.

2.1. Basis for the model

The first law of thermodynamics deals with setting the energy transfers crossing the system boundaries equal to the change of the energy of the system. It is also defined as the amount of energy (Q) added to the system by a heating process less the amount of energy lost by the system to its surrounding due to work (W) done by the system on its surroundings. This difference ($\Delta E_{\text{system}} = Q - W$) is the internal energy of a thermodynamic system which is associated with the random, disordered motion of molecules. The first law of thermodynamics also suggests that energy can be changed from one form to another, but it cannot be created or destroyed. This suggests that the change in the internal energy of the universe ($\Delta E_{\text{universe}}$) is the sum of