Int. J. Production Economics 143 (2013) 72–85

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Assessing the impact of perishability and the use of time temperature technologies on inventory management

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ARTICLE INFO

Article history:
Received 18 November 2009
Accepted 21 September 2010
Available online 1 October 2010

Keywords:
Inventory control
Continuous review policy
Perishable products
Undershoot
Time temperature integrators

ABSTRACT

This paper investigates the impact of product perishability on the known (r,Q) inventory review policy and the benefits of using Time Temperature integrator technology (TTI) on inventory management. We first formulate an (r,Q) inventory model for perishables having a fixed lifetime. Then, we derive the operating costs of the inventory system when a TTI technology is used. We consider here two types of TTI technology: TTI type 1 technology which enables to monitor products' freshness and alert when products are no more fresh and TTI type 2 technology which gives an information on products' remaining shelf lives. We develop a numerical analysis to illustrate the advantages of using the proposed policy without TTI compared to the classical (r, Q) system which ignores the perishability of products. Finally, we study the cost improvement achieved when a TTI technology is deployed.

1. Introduction

Most of inventory systems assume that products can be stored indefinitely to meet future demand. However, in many industrial sectors, products have a limited lifetime. Health care products and foodstuff, for example, are produced to be consumed in a limited lifetime. Due to this specificity, the economic impact of managing perishable products becomes a serious challenge: about $30 billion are lost due to perishable products in US grocery industry (Lystad et al., 2006). van Donselaar et al. (2006) present empirical results on the inventory control rules which are currently used in supermarkets and investigate how the automated store ordering systems could include the feature of products' perishability.

Perishable products are sensitive to temperature conditions in which they are handled and require special storage conditions in order to preserve their freshness. Among this type of products, one may find meat, seafood products, prepared salad, etc. The freshness of this type of products is characterized by the lifetime. Once an item reaches its lifetime, it is considered to be lost (no longer safe for use). In practice, the lifetime is determined by keeping the product in a pre-specified level of temperature and observing throughout time the growth of microbial development under this condition. The time before the microbial development reaches a certain rate, by which the product is considered unsafe for use, determines the lifetime of product. If the product is maintained in appropriate temperature conditions, this lifetime is expected to be experienced by the product throughout the supply chain. However, it may happen that the product is maintained in lower or higher temperature levels than what is expected. As a consequence, the effective lifetime experienced by the product may be smaller or larger than its expected value.

The time temperature integrator technology (TTI) can be defined as a device that can evaluate and/or provide the shelf life or the remaining shelf life of products by monitoring products' temperatures. This evaluation depends on the temperature variations that affect the freshness of products. Actually, since this technology is not commonly used, supply chain actors are taking a large margin of precaution when fixing products' lifetimes. To understand how supply chain actors determine the lifetime of products, Fig. 1 shows an example of distribution of the effective lifetime. When a TTI type technology is not used, the expiry date printed on a product's packaging is based on the margin of precaution that supply chain actors take. For example, taking a margin of precaution equal to 100% means that the product lifetime is fixed to 3 days. That is why, the expiry date printed on the product's packaging will be set equal to 3 days. This does not mean that the product's effective lifetime will be equal to 3 days: as seen from Fig. 1, with a margin of precaution of 100%, the product is actually expected to have a lifetime that is greater than 3 days. The high margin of security of 100% guarantees that the product lifetime will at least be 3 days. If now the margin of precaution is set to 90%, then the product's

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doi:10.1016/j.ijpe.2010.09.032

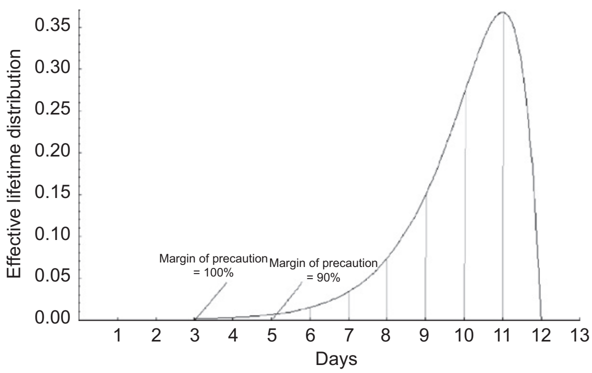

Fig. 1. Example of effective lifetime distribution.

lifetime will be 5 days. Here, we are not sure that the product would be usable up to 5 days, we take therefore a risk of having a product that will perish before 5 days, the probability of this event being 0.10. The trade-off of decreasing the margin level is clear, on one hand, if the margin of precaution is high, that is, the product's lifetime is small, then some products kept in stock are discarded even they are still usable because they are not perished yet. On the other hand, if the margin level is low, then some products are kept in stock while they are already perished. In terms of improvement, as will be explained in more details in Section 4 of this paper, the TTI technology can extend the lifetime of products by reducing the safety margin that producers take in order to determine the products' expiry dates. Hence, products that are perished before their expiry date with a low margin of precaution can be detected by TTI devices and be discarded from the inventory. Extending the lifetime may have an effect on demand rate. In the context of a supermarket for example, we believe that demand may still constant, increases or decreases depending on customers' behavior. Indeed, even if TTI indicates that products are still usable while their expiration date is already exceeded, consumers may not buy these products because such situation does not guarantee the quality of products. As a consequence, the demand rate may decreases or still constant. The demand rate may increases if the lifetime is short, in this case, TTI technologies become a sort of guarantee of the quality and the freshness of products, hence, customers may have more confidence on these products and purchases more.

Another benefit provided by TTI is the cost reduction associated with the outdated quantity and the stock outs. By decreasing the margin level (i.e., increasing the lifetime), the amount of outdated products decreases and as a consequence the frequency of stock outs decreases also. For details about the other potential benefits of using TTI, interested readers are referred to the papers of Sahin et al. (2007) and Taoukis and Labuza (1998).

We aim, in this paper, to analyze the impact of perishability on an inventory controlled by the (r, Q) policy and to answer the question of whether the use of TTI technologies can effectively reduce the total inventory operating cost. To do so, we compare firstly the (r, Q) inventory system which ignores the perishability of products (infinite lifetime) to an (r, Q) system where the lifetime is determined by taking 100% of safety margin (finite and fixed product lifetime), secondly we compare the (r, Q) policy with fixed lifetime to an (r, Q) inventory system where the lifetime is a discrete variable monitored by the TTI technologies. We note that there exists two types of TTI technologies. The TTI type 1 provides information about the lifetime of product by changing color if the predefined rate of microbial development is reached, whereas the TTI type 2 provides the remaining lifetime of product at discrete time interval. The comparison is based on an economic framework defined by the inventory operating costs. When the lifetime of products is fixed, we show that the proposed model without the use of a TTI technology outperforms considerably the (r, Q) with infinite lifetime. When a TTI technology is deployed to monitor the lifetime, the (r, Q) inventory system performs better than in the case of inventory system without TTI.

The paper is organized as follows: in Section 2 we review the literature on inventory control of perishable products. In Section 3, we derive the operating costs of the (r, Q) inventory model without TTI, i.e., Model 1. In Section 4, we study the (r, Q) policy with TTI type 1, i.e., Model 2 and type 2, i.e., Model 3. Finally, an extensive numerical study comparing the performances of these models is conducted. The paper ends with some conclusions.

2. Literature review

Perishable inventory systems are studied extensively in literature. Depending on products' shelf life characteristics, three categories of models can be distinguished:

(1) Inventory models with fixed lifetime where all on hand products with the same age will be disposed of together at the end of their usable lifetime.
(2) Inventory models with stochastic lifetime where each product will fail at the end of his usable lifetime if it is not consumed by demand.
(3) Inventory models with constant or continuous deterioration rate, where the rate of decay is proportional to the on hand inventory or changes according to some function (for example, exponential decay).

In this paper, we consider the first and the second category of perishable inventory models. A relevant literature review under the third degradation type can be found in Goyal and Giri (2001), Raafat (1991).

Nahmias (1982) conducted a comprehensive summary on fixed and random life perishability problem in which, he has classified the different models of perishable inventory into the three categories discussed above. A more general survey on supply chain management of perishable can be found in Karaesmen et al. (to appear). According to the existing works under fixed lifetime, if products cannot be held in stock more than one unit of time, the problem is reduced to the known Newsboy problem. Nahmias and Pierskalla (1973) studied a perishable inventory model where product lifetime is equal to two units of time. Fries (1975) and Nahmias (1975) extended independently the model to the case of three or more units of time, they showed that the computation of an optimal policy requires the resolution of a dynamic program whose state variable has dimension $m-1$ (where m denotes the product lifetime). These works assume that the ordering cost is proportional to the number of units ordered. Nahmias (1978) relaxed this assumption by including the fixed ordering cost. When products can be kept in stock for more than two units of time, the numerical computation of the optimal policy turns out to be impractical. In order to avoid this difficulty, induced by the need to track the different-aged inventory, several research has been focused on heuristic approximations. Nahmias (1976) considered only the total quantity of on hand inventory (without distinguishing products age categories) in order to simplify the computations. In keeping with this trend, Williams and Patuwo (2004) provide a sensitivity analysis of the order quantity regarding to a positive lead time, ordering, holding, shortage and outdating costs in a periodic review perishable inventory with two periods lifetime. They show that the ordering