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A novel mathematical model for a multi-period, multi-product optimal ordering problem considering expiry dates in a FEFO system ☆

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ABSTRACT

One of the main challenges of retail units is to determine the order quantities of different types of products, each with a specific expiry date, so that the system cost including shortage cost is minimized. We study a new multi-product multi-period replenishment problem for a First Expired-First Out (FEFO) based warehouse management system. The proposed nonlinear model is first converted to a linear one and then solved by applying two evolutionary algorithms: the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), in which design parameters are set using Taguchi method. Computational results demonstrate the applicability of the proposed model for perishable items and comparing the results shows the efficiency of the proposed metaheuristics as well.

1. Introduction

In most real world cases, such as restaurants, butcher shops and chain supermarkets different types of products with limited life-times are supplied. Annually, a large volume of food and pharmaceutical products produced worldwide, gets lost or wasted. However, many people die daily due to a poor diet or medical service in some other parts of the earth. Wastes not only result in significant costs and imbalance in supply and demand, but also cause the degradation of the environment and bring about climate change. Designing and planning well-organized inventory systems which can result in getting the right quantity of products of the right quality, from the right source, and having the products delivered to the right place at the right price is a significant step to cope with these challenges (Sazvar et al., 2013a).

An important characteristic of inventory models that directly influences their complexity is the nature of the products. Based on Goyal and Giri (2001), stocks can be categorized broadly into three meta-classes:

(i) unlimited lifetime products, that is, products with indefinite shelf-life;
(ii) style/fashion products, that is, products which lose their value over time, due to the new substitution products introduced by a competitor or rapid changes in technology; and

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(iii) deteriorating products. Deterioration refers to vaporization, dryness, damage, spoilage, etc. of a commodity resulting in decreasing usefulness.

Deteriorating products are classified in two main groups (Goyal and Giri, 2001). Products that have a maximum pre-specified usable lifetime such as some pharmaceutical products and foodstuff are classified as "perishable products". These products perish completely, when they exceed their lifetime. Products with a specified expiry date are therefore categorized as perishable items. Products which have no shelf-life and lose their utility value gradually, like radioactive substances, petrol and gasoline, are classified as "decaying products". A more detailed discussion on classifications of deteriorating products and their characteristics is given in Bakker et al. (2012), Goyal and Giri (2001), Sazvar et al. (2013a,b), and Paul and Voß (2014).

Based on Pahl and Voß (2010), it can be said that all products deteriorate sooner or later, depending on the planning time horizon. When the planning horizon is short, there may be no need to consider such deterioration characteristics. However, in practice, for many products, the time horizon for tactical (and even operational) decisions is long enough and the effects of deterioration play a significant role. Depending on the type of industry, not paying attention to the deterioration of products might result in uncompensated costs of shortage as well as waste and scrap which are the major sources of inventory loss. Lystad Erik et al. (2006) report that deteriorating products account for about $200 billion in sales in the United States grocery industry, about fifteen percent of which is lost due to deterioration. As well, a huge amount of waste or expired products have negative effects on company's reputation and result in losing loyal customers. These general bottlenecks along with destructive effects of deteriorated products on environment make development of effective inventory systems for deteriorating items as one of the main concerns of subject matter experts. However, identification of an optimal ordering policy for these products is usually complicated, specially for multi-product situations. It is even more difficult when the demand is assumed to be dynamic (Bakker et al., 2012).

A growing number of deteriorating items in retail unit's (e.g. pharmacies, chain stores, butcher shops and chemical units) shelves is those with a pre-specified expiry dates. In the case of such time-sensitive products, in order to control inventories and respond to demands, two conditions should be sustained: (1) enough in-stock inventories should be available in the warehouse to cope with the customer demand and avoid undesirable shortage. For this purpose a real time (computer based) or periodic (traditional systems) tracking should be done regularly for in-stock inventory levels, and (2) the expiry dates of in-stock inventories should be controlled within the planning horizon to avoid encountering undesirable useless, perishing products which with extra cost exposes discarding cost to the system and brings about negative effects on company's reputation.

For this purpose, a specific pickup policy for perishable items which plays a significant role in inventory system costs through its direct impact on the amount of perished items is necessary. In some situations, specially in chemical and pharmaceutical industries where expired dates are determined based on batch expired date or shelf lifetime, a First Expired-First Out (FEFO) policy is applied. According to the FEFO policy, products which are to expire soon should be served or removed from stock on a priority basis.

When the variety of perishable products (each one by its own expiry date) increasing, physical limitations like warehouse capacity are critical, and a decision should therefore be made based on distinct criteria, which include profitability, expiration dates and dynamic demands satisfaction. In other words, the problem is how to properly assign limited capacity of warehouses to different products each with its own remaining lifetime, its specified occupying space, profitability and shortage cost to fulfill the dynamic demands of customers in a cost-effective manner. In such situations, the main concern of retail unit managers are: How they can adjust an ordering policy not to face a high amount of perished items on one hand, and not have a large amount of unfulfilled demand (shortage) on the other? Which quantities of which products under which policy must be replenished simultaneously, and at which time period is this possible? What proportion of warehouse capacity should be assigned to a product with a specific expiry date to optimize the total system's costs including ordering, procurement, holding, shortage and waste costs?

This paper addresses the replenishment problem for products with expiry dates in a multi-product multi-period environment under FEFO policy in a dynamic demand scheme and by considering shortage cost and a capacitated warehouse, which is an extremely significant problem from the theoretical and practical viewpoints. While there are a broad range of studies dedicated to this type of problem, to the best of our knowledge, the great deal of such researches have been devoted to some of its aspects separately or to their specific combinations. In addition, going through literature shows that the most of prior mathematical models on replenishment policy for perishable items, have a limitation which cannot adopt a very practical policy called FEFO, even if they have taken the advantage of FEFO policy, some important parts of the system cost like shortage cost, expiration cost, and minor and major ordering cost are neglected. So, there is a gap between the practical and theoretical contributions responsible for developing such models. The purpose of the paper is to tide over this gap by introducing a framework that is a realistic alternative to the more sophisticated complex inventory models. To deal with this real-world problem, a new approach is developed to formulate it as a nonlinear mixed integer mathematical model. Thereafter, by applying some theoretical methods, the primary nonlinear model is converted to a more tractable linear model. Due to the computational complexities arising for large scale problems, two popular efficient metaheuristic algorithms are built to find competitive near-optimal solutions in a reasonable time.

The rest of the paper is organized as follows. In the next section, we review some of the related researches in the field of replenishment policies and inventory planning. The motivation and contribution of this work is then described in detail in