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Review on Inventory control for a non-stationary demand perishable product

Mr.Muragesh Math [1], Dr.D.Gopinath[2], Mohammed Safiya[3]

[1,3] Research Scholar, Dept.of Mathematics and Statistics,Chaitanya (Deemed to be University), Telangana,India

[2]Associate Professor ofStatistics, Chaitanya(Deemed to beUniversity),Telangana,India.

Corresponding Author:
Mr.MurageshMath
Research Scholar, Dept.of Mathematics and Statistics,Chaitanya (Deemed to be University), Telangana, India
ORCiD
https://orcid.org/
0000-0002-5672-1750
Mail: murageshmathapati5@gmail.com

ABSTRACT

We consider the periodic-review, single-location, single-product, production/inventory control problem under non stationary demand and service-level constraints. The product is perishable and has a fixed shelf life. Costs comprise fixed ordering costs and inventory holding costs. For this inventory system we discuss a number of control policies that may be adopted. For one of these policies, we assess the quality of an approximate Constraint Programming (CP) model for computing near optimum policy parameters.

INTRODUCTION

Perishable Goods production lead long, short sales, unsold at the end of the period the residual value is very low even need to deal with the cost, uncertainty of market demand significant characteristics of a class of goods collectively. Vendors often launched a marketing strategy for perishable products with the continuous depreciation of the characteristics of the passage of time, resulting in consumer demand for such commodities is divided into two phases, known as non-stationary demand. In the early-to-market, the demand is random. Sales final, to maintain the original price, the commodity may decrease in sales even unmarketable. If the merchandise cannot be finished on schedule sales, vendors will be the cost of the loss of goods or to assume a high level of long-term inventory costs, the amount of funds used. Therefore, the use of discounts and other sales Chamber of Commerce in this stage of the merchandise promotions. The study found that this stage of the market demand and commodity prices, inventory levels related. For sellers, early in the sales should order the number of goods, how to develop a reasonable initial price, as well as how to dynamically develop late in the sales discount prices, making their losses to a minimum or profits while stimulating demand reaches the maximum? This paper attempts to solve practical problems. First, the perishable products are divided into three categories: perishable commodities, respective characteristics and common characteristics of seasonal goods, festive goods, review three categories of goods, demand characteristics, related technologies and their inventory control in a non-stationary demand . Second, the study of two-phase non-stationary demand under seasonal merchandise inventory control problem. The first phase of research customer perceived value, customer arrival rate and customer total set of potential demand obedience binomial distribution, to reduce inventory risk as a starting point, to seek the optimal initial order quantity and the initial pricing; second stage , proposed the concept of loss rate, to consider comprehensive number of losses and the time value of money and other factors set the market demand is dependent on commodity prices and stock levels. Within several pricing plan, the pricing time interval equal. Minimizing the loss of profits as the objective function, the establishment of the consolidated loss rate is based on time-varying seasonal items ordered two-stage dynamic pricing model. Then the introduction of the particle swarm algorithm for solving example is given to analyze the changes in inventories of goods in both cases can be returned to the manufacturer and cannot be returned to the manufacturer and Ordering pricing strategy.

Food supply chains of processed fresh products generally include primary production (farmers), food processing industry, distribution centres of the producer or a retail organisation, retail stores and consumers (e.g. (van der Vorst et al., 2000)). In this paper we study the practical production/inventory control problem faced by a food producer. After processing fresh ingredients into a final product and packing the product, the producer prints a best-before-date on the package of the product. Products can be meat, dairy products, fresh fruit juices and produced fresh meals. If the product is stored and handled under the required conditions, the product is presumed to have a fixed lifetime; the best-before-date is determined by adding a fixed number of days to the production date. In practice, a food producer often faces a non-stationary stochastic demand for his products, caused by, for instance, promotional activities of the retail organisation, or weather conditions. The producer has to decide at any given period (e.g. a week) whether to produce or not, and if so, how much to produce. This decision depends on the forecast of the demand, on the agedistribution of the items in stock and is influenced by factors such as the setup cost of a production run and the perishability of the product. Food producers often have contracts with their customers, regarding delivery performance including service level and remaining shelf life. In order to meet these requirements and to determine production quantities, the producer has to balance product waste (as a result of too much inventory) and out-of-stock (as a result of too little inventory). Due to the perishability of the product, it is likely that the inventory of final products at the producer consists of items of different ages, that is, with different production dates. The producer sells the products to the customers (e.g. supermarkets) with a guaranteed remaining shelf life on the time of delivery. We define internal shelf life as the maximum time span between production and distribution. To guarantee a minimum remaining shelf life at the customer, one sets a maximum on the internal shelf life. For an internal shelf life of just 1 period, one can follow the order policy of the so-called Newsboy Problem (Silver et al., 1998) that produces every period with an order quantity that takes the perishability into account. When the internal shelf life is longer than 1 period, the order policy depends on the setup cost and holding cost and the aging of the products (Fries, 1975). When setup cost is relatively high, the optimal order policy for a product, disregarding perishability, may lead to a time between two production runs that exceeds the internal shelf life. In that case a part of the production quantity may become waste. Waste may lead to out-of-stock in the periods before a new production run is planned.

LITERATURE REVIEW

In order to construct a model for the practical problem under consideration, we review literature that deals with a combination of the key characteristics of the practical problem: perishability with a fixed lifetime, fixed setup or ordering cost, non-stationary demand, periodic review and a service-level constraint. Nahmias (1982), Goyal and Giri (2001), Karaesmen et al. (2011) and Bakker et al. (2012) reviewed the literature on inventory models for perishable products with a fixed lifetime. Almost all papers surveyed assume stationary demand, i.e. demand in successive periods is an independent identically distributed random variable. Tekin et al. (2001) formulated an agebased control policy with a continuous review for perishable products with a fixed lifetime, under service-level constraints.

The aging starts after unpacking the batch for consumption. As long as the items are packed in stock, the lifetime is virtually infinite. In early works e.g. Nahmias (1975) and Fries (1975) observe that in general an optimal order policy for perishables with a fixed life time should take the ages of the products in stock into account. Even when all perishable items are of the same age, base stock polices are not optimal, as argued by Tekin et al. (2001) and Haijema et al. (2007). Broekmeulen and Van Donselaar (2009) suggest a replenishment policy for perishable products at a retailer, which takes the quantity and the age of the items in inventory into account. They assume negligible fixed ordering cost. The demand is assumed to be stochastic, with a weekly demand pattern per day, but stationary expected demand per week. They apply the same safety stock for each weekday.

Haijema et al. (2007) developed an optimal policy for the periodic production and inventory of blood platelets. They combine two types of demand, each of which requires a different issuing policy. The demand distributions they consider have a weekly demand pattern per day, but are stationary across weeks. In Haijema et al. (2009) the approach is extended for non-stationary demand considering holidays and other events. Any fixed production cost is neglected. In Haijema (2011) fixed order cost are studied and a new class of order policies is presented. In none of these papers service-level constraints are included. Minner and Transchel (2010) present a numerical approach to determine replenishment quantities for perishable products in retail dynamically, using a weekly demand pattern. They consider service-level constraints varying for different intra-period time points and for different periods. Fixed ordering cost is assumed to be negligible.

In our investigation, the combination of non-stationary demand and a service level approach in inventory models was mainly found in literature about non-perishable products. Neale and Willems (2009) argue that non-stationary demand is very common nowadays. Therefore they developed a non-stationary supply chain inventory model, by formulating a single-stage inventory model that serves as a component of a multistage system, using service-level constraints to calculate safety stocks.

The model is based on Graves and Willems (2000) and closely related to Graves and Willems (2008). Every stage has a base-stock policy with a review period of 1 time unit. The base-stock level is an order-up-to level to cover demand in upcoming periods. The safety stock is calculated as a function of demand over the preceding periods. In the multi-stage system Neale and Willems (2009) minimise the total holding cost of the safety stock in all stages and periods. They do not consider setup cost, which is an important cost component in practice. Bookbinder and Tan (1988) studied single-stage probabilistic lot-sizing problems, where they included setup cost, and service-level constraints. They developed a “static-dynamic” uncertainty model, splitting the problem in two stages. The first stage determines when to order, the second how much to order.

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Tarim and Kingsman (2004) considered the Bookbinder and Tan approach as a basis for the formulation of a mixed integer programming model for non-stationary stochastic demand for the simultaneous determination of the number and timing of the replenishment orders. In contrast to Bookbinder and Tan's heuristic approach, Tarim and Kingsman's approach provides an optimal solution. Several extensions of Tarim and Kingsman's model exist. Rossi et al. (2011b) and Tarim et al. (2011) proposed efficient and complete special purpose algorithms. Tempelmeier (2007) used Tarim and Kingsman's model as a basis to formulate different types of service-level constraints. Rossi et al. (2010) and Rossi et al. (2011a) incorporated a stochastic delivery lead time and developed both complete and fast heuristic approaches. Tempelmeier (2011) incorporated supplier capacity constraints. Pujawan and Silver (2008) proposed a novel and effective heuristic approach. However, to the best knowledge of the authors, no paper deals with all aspects of the practical planning problem under consideration: the combination of perishability with a fixed lifetime, fixed setup or ordering cost, non-stationary demand and a service level approach. In this paper we extend the model of Tarim and Kingsman towards a model that includes non-stationary stochastic demand for a perishable product under a FIFO issuing policy.

STOCHASTIC PROGRAMMING (SP) MODEL

The basis of our study is a fill rate variant of a Stochastic Programming (SP) model presented in [4] for a practical production planning problem over a finite horizon of T periods of a perishable product with a fixed shelf life of J periods. Items of age J cannot be used in the next period and are considered waste. Demand is stochastic and non-stationary, as it changes over time. To keep waste due to out-dating low, one issues the oldest product first, i.e. FIFO (first in, first out) issuance. Literature provides many ways to deal with perishable products, order policies and backlogging, e.g. [1,3,7]. The model we investigate aims to guarantee a β-service level constraint; the supplier guarantees expected shortage not to exceed (1 − β)% of the expected demand for every period. Not fulfilled demand is lost. The solution for such a model is a so-called order policy. We consider a policy with a list of order periods Y with order quantities Qt. The question is to derive a set of order quantities that leads to minimum cost and fulfils the service level constraint.

STOCHASTIC DYNAMIC PROGRAMMING (SDP)

which extends and complements the discussion of Rossi (2013), focuses on the case of a single perishable item with fixed shelf-life. We consider fixed and variable ordering costs as well as holding and penalty costs for backordered products; the demand is non-stationary over a finite set of periods; inventory is issued following the FIFO policy. A major difference with respect to Rossi (2013) is the adoption of a penalty cost scheme in place of a service level constraint; furthermore, we present a broader set of instances and we assessed the quality of our new heuristics against optimal solutions obtained via stochastic dynamic programming. We make the following contribution to the literature on perishable item non-stationary stochastic lot sizing.

• We introduce exact analytical expressions to compute the expected value of the inventory for different product ages when a product can age indefinitely; the expressions work under discrete as well as continuous demand distributions.

• We derive an analytical approximation for the case in which the product age is discrete and finite.

• By using the former results, we extend Silver's heuristic (Silver 1978) to the case in which the product is perishable; in particular we introduce analytical and simulation-based variants of the approach.

• We conduct an extensive numerical study which demonstrates that our new heuristics lead to a cost that, on average, is 5% higher than the optimal cost.

we study the single-item single-stocking location non-stationary stochastic lot sizing problem for a perishable product. We consider fixed and proportional ordering cost, holding cost, and penalty cost. The item features a limited shelf life; therefore we also take into account a variable cost of disposal. We derive exact analytical expressions to determine the expected value of the inventory of different ages. We also discuss a good approximation for the case in which the shelf-life is limited. To tackle this problem we introduce two new heuristics that extend Silver's heuristic and compare them to an optimal Stochastic Dynamic Programming (SDP) policy in the context of a numerical study.

Although in Inventory Control literature, focus is often on infinite horizons with stationary demand, in the reality of retail, demand of perishable food products is typically non-stationary, i.e. uncertain and also fluctuating, partly due to promotions. In this case, we can consider the planning problem as a finite horizon problem with non-stationary demand. The contribution of this paper is to outline a practical inventory control problem of perishable products as a Stochastic Programming (SP) model with a finite horizon and evaluate several solution approaches from earlier studies to handle it. We focus on perishable products that are processed and get a best-before-date on their package, such as packed cheese, cut and packed lettuce, yoghurt, etc. Those products have a fixed maximum shelf life. Producers and retail organisations have arrangements regarding delivery performance, including the necessary available shelf life for the consumer and the service level. After the maximum shelf life M, the product cannot be used anymore for the intended purpose and is considered

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waste. An α-service level requirement refers to the probability to be out of stock, i.e. it should be smaller than 1 – α. This implies we are dealing with a chance constraint for each period. For every period (day, week, ...) the producer has to decide whether or not to order and how much, considering a fixed ordering cost, holding cost and disposal cost. This results in replenishment cycle lengths of a varying number of periods. The producer has control over the issuing of products, so in order to minimise waste, a First-in-First-Out (FIFO) policy is used. Excess demand is backlogged. The question is what are the most appropriate inventory policies to handle the inventory control problem in practice.

For products with non-stationary demand, order decisions and production planning will fluctuate, especially for perishable products where smoothing of ordering or production is impossible, because the older items in stock can perish. The fluctuations in demand ask for a specific strategy. Bookbinder and Tan (1988) distinguish three strategies to deal with ordering of non-perishable products with nonstationary demand in a periodic review. The first strategy is called the static uncertainty strategy; the timing and size of the orders are set at the beginning of the time horizon. The replenishment schedule defines when to order beforehand, denoted by Yt = 1 when an order is placed and Yt = 0 if not. This results in replenishment cycles Rt of different length. In case of long lead time, adaptation of the order quantity just before demand is not possible, so also the production quantity is determined at the beginning of the planning horizon. We call this a YQ policy. We use the variable Y in the policy name instead of R to make clear that for every period a decision is made. This policy is appropriate when there is considerable lead time and is investigated in (Pauls-Worm et al., 2016). The second strategy to deal with non-stationary demand is the static-dynamic uncertainty strategy, where timing of the orders is set at the beginning of the time horizon, but the order quantity may be adapted in response of the inventory levels observed during the time horizon. We call this a YS policy. In a heuristic approach, Bookbinder and Tan (1988) split the problem in two stages. The first stage determines the timing and the second the quantity. Tarim and Kingsman (2004) considered this approach as a basis for an MILP model formulation for non-stationary stochastic demand for the simultaneous determination of the timing and size of the replenishment orders. The third strategy to deal with non-stationary demand is the dynamic uncertainty strategy where the order quantity is decided at the beginning of every period. We call this a Q(X) policy, where X is the inventory level at the beginning of the period. A policy according to the dynamic uncertainty strategy is discussed already in the 1960s. Karlin (1960a) shows that a critical number policy is optimal, were the critical numbers are a reorder level st, and an order-up-to level St, resulting in an (R,st,St) policy. Karlin (1960b) and Veinott Jr (1963, 1965) developed optimal myopic policies for certain cases. Morton (1978) shows that near myopic bounds are close to optimal, under the assumption of disposal of excess stock. Morton and Pentico (1995) derive nearmyopic bounds for the more general case. Zipkin (1989) developed optimal critical number policies for a cyclic demand pattern. He shows that the critical numbers in the optimal policy smooth the fluctuation in the demand data. This “wait-and-see” approach in the critical number policies following the dynamic uncertainty strategy could require an order with setup cost in almost every period. This might be undesirable for the production planning of a company, but in case of large setup cost relative to the holding cost, this is neither optimal (Bookbinder and Tan, 1988). Bookbinder and Tan (1988) formulated their strategies for non-perishable products. Perishable products require special attention with respect to order policies taking non-stationary demand into account. Order policies for perishable products with a fixed lifetime are reviewed by Nahmias (1982), Goyal and Giri (2001), and Karaesmen et al. (2011). Almost all papers assume stationary demand. Fries (1975) shows that with a maximum shelf life of $M \geq 2$, neither an (R,S) nor an (R,s,S) policy is optimal. Nahmias (1975) and Fries (1975) observe that in general an optimal order policy for perishable products with a fixed life time should take the age-distribution of the products in stock into account. Even when all perishable items are of the same age, base stock (order-up-to level) policies are not optimal, as argued by Tekin et al. (2001) and Haijema et al. (2007). Some papers, e.g. (Haijema et al., 2007), (Broekmeulen and van Donselaar, 2009), (Minner and Transchel, 2010) assume a cyclic demand pattern, with a weekly demand pattern per day, but stationary expected demand per week. They assume negligible setup cost and follow a dynamic uncertainty strategy, which might not be optimal in case of fixed setup cost.

Food producers often have contracts with their customers, regarding service level. From the above mentioned papers, only Bookbinder and Tan (1988), Tarim and Kingsman (2004) and Minner and Transchel (2010) consider service level constraints. The other papers use penalty cost for each backlogged item. Unfortunately, the size of a penalty to guarantee a desired service level is not straightforward to determine as in general when dealing with chance constraints. Pauls-Worm et al. (2014) presented an SP inventory model that minimises the expected total costs, including setup cost, unit procurement cost, holding cost and cost of waste, for a perishable product with non-stationary stochastic demand with an α-service level constraint under a FIFO issuing policy. A YS policy is convenient in practical planning for a food producer; one knows beforehand in which periods to produce. Using an order-up-to level S defines a practical rule to determine the order quantity taking uncertainty into account. In Pauls-Worm et al. (2014), we used an MILP approximation to derive values for a YS system, based on the cumulative distribution function (cdf) for the demand during the replenishment cycle and the expected age-distribution of the inventory during the replenishment cycle. However, we know that

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this approach may fail in meeting service level requirements because the approximated amount of waste is underestimated and the amount of fresh items is overestimated, due to Jensen Inequality. Therefore, we presented in (Hendrix et al., 2015) a computational method based on the so-called Smoothed Monte Carlo method with sampled demand to optimise values for a YS system. The resulting MINLP approach uses enumeration, bounding and iterative nonlinear optimisation. The order quantity is determined by order-up-to level S minus the total inventory in stock. However, it could be more cost-efficient to consider the age-distribution of all items in stock in determining the order quantity. Let X denote the inventory age-distribution at the beginning of a period. Using a sample based YQ(X) policy, one can take the age-distribution into account. Finally, we can consider a more flexible Q(X) policy according to a dynamic uncertainty strategy, derived by SDP. A Q(X) policy determines the order quantity at the start of every period based on the age-distribution of the items in stock. Besides variation in uncertainty strategy, the presented policies vary in ease of implementation in practice. An order-up-to level policy requires only information about the total available inventory and a set of orderup-to levels St. When the age-distribution is considered in the policy, information is required about the age-distribution of items in stock, and an order quantity has to be determined applying a table or computation process. With the extra information required, also the calculation time to find a solution may increase.

CONCLUSION

This paper studied a periodic review inventory system for perishable products with correlated demand on a finite horizon. We consider the periodic-review, single-location, single-product, production/inventory control problem under non stationary demand and service-level constraints. The product is perishable and has a fixed shelf life. In this system, a fixed quantity of products from the supplier is received in each period. This quantity must be determined before the first period and cannot be changed thereafter. The inventory level can be adjusted through purchasing and selling products in an electronic marketplace at the beginning of each period. The available supply and demand quantities in the electronic marketplace depend on the prices offered by the retailer. The retailer's optimal purchasing and selling quantities, and respective prices in the electronic marketplace are computed, and the expected total cost is shown to be convex with respect to the order quantity from the supplier, which enables an efficient algorithm in obtaining the optimal order quantity. Numerical experiments show that greater cost savings from electronic marketplace are obtained when demands in different periods are strongly correlated and greatly differ from each other. Variousresearches done on this area also discussed in this paper.

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