

**DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED
SCIENCES**

**THE NEWSVENDOR PROBLEM FOR
RESALABLE PRODUCTS WITH CONFLICTING
OBJECTIVES**

**by
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İZMİR**

THE NEWSVENDOR PROBLEM FOR RESALABLE PRODUCTS WITH CONFLICTING OBJECTIVES

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “**THE NEWSVENDOR PROBLEM FOR RESALABLE PRODUCTS WITH CONFLICTING OBJECTIVES**” completed by **MUTLU KARA** under supervision of **ASSIST. PROF. DR. UMay UZUNOĞLU KOÇER** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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THE NEWSVENDOR PROBLEM FOR RESALABLE PRODUCTS WITH CONFLICTING OBJECTIVES

ABSTRACT

Because of the developing marketing strategies, competition policies of enterprises are focused on meeting customer expectations at the highest level. In this context, the case that customers return the products they purchased for any reason is being increasingly common recently within the marketing strategies of several enterprises. For this requirement, determining the inventory policies by using newsvendor model for returned products is widely used in the literature.

The newsvendor problem is one of the fundamental models in stochastic inventory theory. In this model, the order quantity which optimises the single period expected profit or cost function is calculated. Since the demand for some products is seasonal, inventory planning of this type of products is done for a single period. Different objectives have been developed to satisfy changing requirements, for newsvendor problem apart from the classical approach that optimizes the expected cost or profit function. Most frequently used alternative objectives can be explained as the order quantities that maximises target profit or the probability of exceeding expected profit.

In this study, the newsvendor problem will be examined with respect to resalable returns and the optimal order quantity that maximises the probability of exceeding the expected profit will be searched. Later, the order quantity that balances the contradictory purposes, the order quantity that maximises the expected profit and the quantity amount that maximises the probability of exceeding the expected profit, will be researched. By simulated demand data, order policies are determined, and sensitivity analysis for model parameters as well as economical interpretations are presented.

Key Words: The newsvendor problem, resalable returned products

ÇELİŞEN AMAÇLAR ALTINDA TEKRAR SATILABİLİR ÜRÜNLER İÇİN GAZETECİ ÇOCUK PROBLEMİ

ÖZ

Gelişen pazarlama stratejileri doğrultusunda firmaların rekabet politikaları, müşteri beklentilerini en yüksek düzeyde karşılamak üzerine odaklanmıştır. Bu bağlamda, müşterilerin satın aldıkları ürünü herhangi bir sebeple belli bir süre içinde iade etmeleri durumu, firmaların pazarlama stratejileri içinde günümüzde giderek yaygınlaşmaktadır. Bu gereksinim doğrultusunda iade edilen ürünler için gazeteci çocuk problemi ile envanter politikası belirlenmesine ilişkin çalışmalara literatürde sıkça rastlanmaktadır.

Gazeteci çocuk modeli stokastik envanter teorisinde temel modellerden biridir. Bu modelde tek-periyotlu beklenen kâr ya da maliyet fonksiyonunu eniyileyen sipariş miktarı hesaplanır. Bazı ürünlere olan talep sezonluk olduğundan, bu tip ürünlerin envanter planlaması tek periyot için yapılır. Gazeteci çocuk problemi için beklenen kâr ya da maliyet fonksiyonunu eniyileyen sipariş miktarının araştırılmasının yanı sıra, ihtiyaçlar doğrultusunda farklı amaç fonksiyonları geliştirilmiştir. En sık rastlanan alternatif amaçlar, hedef kârı ya da beklenen kârı aşma olasılığını maksimize eden sipariş miktarının araştırıldığı modellerdir.

Bu çalışmada, tekrar satılabilir iade ürünler için gazeteci çocuk modeli, beklenen karı enbüyüklemek ve beklenen karı aşma olasılığını enbüyüklemek amaçları doğrultusunda ayrı ayrı incelenerek iki ayrı amaç için sipariş politikaları belirlenmiştir. Yanı sıra, çelişen bu iki amaç fonksiyonunu birlikte optimize eden dengeleyici bir sipariş miktarı araştırılmıştır. Türetilmiş talep verilerinden hareketle sipariş politikaları belirlenmiş, modelin parametrelerine ilişkin duyarlılık analizleri ve ekonomik yorumlamalara yer verilmiştir.

Anahtar Kelimeler: Gazeteci çocuk problemi, tekrar satılabilir iade edilmiş ürünler

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CHAPTER ONE

INTRODUCTION

Enterprises have some necessities to realise in order to sustain their subsistence in the highly competitive market conditions. Providing rapid responses to the demands of the customers is of great importance among these necessities. Therefore, enterprises should maintain particular economic assets operational at any time. These resources and products of economic value, enterprises hold for satisfying the demands of the customers at the right time, are called the *inventory*.

The inventories that enterprises hold operational have various costs. Holding more than adequate inventories causes losses in return of the dead stock at low prices at the end of the season as well as a considerable carrying cost. On the other hand, deficiency in inventories causes the demands not to be satisfied in a timely manner and thus affects the reputation of the enterprise negatively. The need for inventory management rises to the occasion just at this point. The goal of the inventory theory is to develop models for the management to minimise the inventory-originated costs and at the same time to satisfy the customers' demands in a timely manner. Enterprises use these models to check and administer their inventory aright.

Inventory models can be classified as *deterministic* and *stochastic*. If the rate of the demand in unit time is known exactly, the model is classified as *deterministic*; otherwise, if the demand in unit time is random, it is classified as *stochastic*.

The newsvendor problem is one of the fundamental models in stochastic inventory theory. In this model, the order quantity which maximises (minimises) the single period expected profit (cost) function is calculated. The principal example given in explaining the single period stochastic inventory model is the newsvendor analogy. According to this example, the newsvendor orders the amount of newspaper that he could sell in a day. If he orders more than he could sell, he cannot sell the newspapers that remain unsold on the other day, and he bears the loss. If he orders less than he could sell, he cannot satisfy the demand, and he bears the cost caused by

loss of sales. Due to this analogy, the single period stochastic inventory problem is called “newsvendor problem” in the literature.

The prevalent goal in the newsvendor model is to determine the order quantity that maximises (minimises) the single period expected profit (cost). As the literature is reviewed it is seen that the interest in newsvendor model has been increased recently; and the model has been re-interpreted towards various purposes. For Khouja (1999), expansions of the newsvendor model to various topics may be classified as follows:

- Extensions to different objectives and utility functions.
- Extensions to different supplier pricing policies.
- Extensions to different news-vendor pricing policies and discounting structures.
- Extensions to random yields.
- Extensions to different states of information about demand.
- Extensions to constrained multi-product.
- Extensions to multi-product with substitution.
- Extensions to multi-echelon systems.
- Extensions to multi-location models.
- Extensions to models with more than one period to prepare for the selling season.
- Other extensions.

One may observe that some of the studies may be counted in more than one of the given categories. In such a case, the study may be counted in one of the related categories with respect to the prevalent purpose. This study is, predominantly, one that can be examined under the first category given above.

There are numerous studies on extensions to different objective functions in the literature. Among them; cases in which the demand variable follows different distributions; cases in which different cost (profit) functions are examined;

newsvendor model for more than one goods; and newsvendor model for returnable goods may be listed.

As it is known, the purpose of the classical newsvendor problem is to determine the optimal order quantity by maximising the expected profit. However researchers have observed the approach that maximises the expected profit function is insufficient in real life conditions. Lanzilotti (1958), performed interviews with the leading enterprises of that time and offered the conception of “target profit” instead of “profit maximising” in his study. In the forthcoming years maximising the probability of achieving target profit has established its presence in many studies. There are also studies on various activity criteria, risk limits and benefit functions.

Kabak & Schiff (1978) are the first researchers that study the probability of achieving target profit (satisficing, aspiration-level). In this study the distribution of demand follows the exponential distribution. Kabak and Schiff grounded their studies on the experimental studies by Wells (1968), Schiff & Lewin (1970); and theoretical studies by Coplan (1968) and Williamson (1970).

For “Aspiration-level” purposes, Lau (1980) developed mathematical formulations on achieving optimal solutions under the assumption of different demand distribution rates; Lau & Lau (1988) and Li et al. (1991) however, implemented this method for two different products. Similar to Lau (1980), Norland (1980) too, developed mathematical formulations for optimal order rates but used normal distribution for demand distribution.

As for Parlar & Weng (2002), they presented a new study under the light of the aforementioned studies. They denominated the purpose of maximising the expected profit as “classical purpose” and reinterpreted the “aspiration-level” purpose in a different manner. As it is mentioned before, “aspiration-level” purpose means maximising the probability of exceeding the target profit. Parlar & Weng (2002), stretched out the “aspiration-level” purpose, since it wouldn’t always be possible to designate a target profit. According to this conception, instead of designating a target

profit, the use of “expected” profit is found appropriate. Put another way, the reinterpreted “aspiration-level” purpose became maximising the probability of exceeding the expected profit. The classical purpose and the reinterpreted “aspiration-level” purpose, which seem contradictory, were “balanced” by the method developed by Parlar & Weng (2002) and they attained a new optimal solution which optimised both of the purposes.

Notwithstanding that the main focus point of enterprises is profit maximisation; there are some special practical occasions they face with respect to their sales policies. When the forms of sale of the enterprises are examined, one may confront various cases. There are cases in which some enterprises accept return their products under some conditions. Also, the customers have the legal right to return the goods in a given period. In such cases, enterprises pay back all or some of the price with respect to the condition of the returned goods. When the newsvendor problem is adapted for the returnable goods, it is seen that some changes would occur in demand estimations and cost accounting.

One may not come across examples of the adaptation of the newsvendor model for the returnable goods in the literature. The first study that the newsvendor model had been implemented for returnable goods was conducted by Vlachos & Dekker (2002). Vlachos & Dekker (2002) used two limiting hypotheses in their studies: the former is a constant percentile of the sold goods is returned whereas the latter is the goods can be re-sold only once. Similarly Mostard & Teunter (2004) implemented the newsvendor model for returnable goods. In opposition to Vlachos & Dekker (2002), Mostard & Teunter (2004) did not offer any assumptions on returns.

In this study, the newsvendor problem will be examined with respect to resalable returns and the optimal order quantity that maximises the probability of exceeding the expected profit will be searched. Later, the order quantity that balances the contradictory purposes, the order quantity that maximises the expected profit and the quantity amount that maximises the probability of exceeding the expected profit, will be researched.

The following chapters of the study is organised as follows: Chapter two will deal with the newsvendor problem for resalable returns after examining the problem with respect to classical and different purposes. In chapter three, the probability of exceeding the expected profit and the inventory policy that maximises the expected profit are designated for the simulated demand data; and the sensitivity analyses for the parameters of the model are presented. Lastly, the results obtained are presented in chapter four.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Inventory Models

The purpose of the Inventory Theory is to offer to the management, the policies that can minimise the costs related to the inventory and that can satisfy the customer demand. These rules are conceptually the “quantity” and the “time”. Put another way, an ideal inventory policy gives the answers to the questions “how large the order should be?” and “when to place an order?”.

It was mentioned in chapter one that the inventory models can be classified as deterministic or probabilistic with respect to the demand’s condition. Probabilistic Inventory Models may be investigated in two categories; Periodic Review Models and Continuous Review Models.

In the Periodic Review Inventory system, the quantity of the inventories on hand has no importance in determining the order policy. The time of reorder; in other words, the period between two orders is defined before the process begins and the orders are placed periodically in the predefined times. However not every order is the same in terms of quantity. Accordingly, the inventory policy may be defined as “placing an order that sets the inventory level to q by checking the inventory level in each time period t ”.

On the other hand, in Continuous Review Inventory systems, the inventory level on hand is constantly kept under control. The factor that determines the time for placing an order is the inventory level which can be defined as “reorder point”. If the quantity of inventory in stock falls down to the reorder point r , the quantity of q is placed as order. For each order, the time between orders may vary whereas the order quantity remains the same. Accordingly, the inventory policy may be defined as “placing an order of quantity q when the inventory level falls down to r ”.

In both inventory systems mentioned above, there are orders that are repeated in more than one period. The newsvendor model, since it is a single-period model, appears in a different structure among the stochastic inventory models and it enables us to do planning only for a single period.

2.2 The Newsvendor Model

The newsvendor problem deals with determining the amount of economical orders for the seasonal goods. One may want to determine an optimal inventory decision for just one period or for some particular season. For instance, for calendars or datebooks printed for New Year, or textile goods such as swimsuits ordered for the summer season, a seasonal inventory planning is required.

In these situations, a decision maker is faced with the problem of determining the order quantity q . After q has been determined, demand (X) which is a random variable is observed. Depending on the values of X and q , the decision maker incurs a cost $c(x, q)$. We assume that the person is risk-neutral and wants to choose an order quantity to minimize his or her expected cost. Since the decision is made only once, this type of model is called a *single-period decision model* (Winston, 2004).

Newsvendor model is the single period inventory model. Another one of the main features of the model is the demand variable being stochastic. Also the model is examined according to the demand variable being discrete or continuous random variable. Some assumptions on newsvendor model may be listed as below:

- a) At the end of the period the unsold goods out of the ordered ones are counted as either loss (zero profit) or they are returned at some particular price (generally at a very low price than it costed).
- b) The goods should be sold in the period in which they have been ordered.
- c) Although the demand is uncertain, it is assumed that it follows a particular probability distribution (normal distribution, exponential distribution, etc.)
- d) In case the ordered goods are sold out, if the vendor faces a “sell out” against its customers, it is assumed that this situation would bring certain costs to the vendor.

In the following sections of this Chapter the classical approach to the Newsvendor model, which concerns about determining the order quantity that would minimise the annual expected cost (cost minimisation) when the demand variable is discrete and continuous, will be emphasised; later on the determining of the optimal order policy in cases of optimizing the different objective functions will be approached about. At the end, “the optimal order quantity which maximises the probability of the expected profit for resalable return goods”, which is the subject of this study will be presented.

2.2.1 The Classical Approach to the Newsvendor Model

The main method in the newsvendor model is to determine the optimal order quantity that minimises the expected cost or maximises the expected profit. As it is mentioned before, the model is examined in two ways depending on the demand variable being discrete or continuous.

2.2.1.1 Discrete Demand Case

X is the random variable representing the demand, and q is the order quantity, $c(x, q)$ is the cost function. If the demand is discrete random variable, $c(x, q)$ leads to:

$$c(x, q) = c_o q + (\text{terms not involving } q) \quad (x \leq q) \quad (2.1)$$

$$c(x, q) = -c_u q + (\text{terms not involving } q) \quad (x \geq q + 1) \quad (2.2)$$

(Winston, 2004)

c_o , is defined as the overstock cost per unit. In case $x \leq q$, it means that more orders than the demanded are placed. If the order quantity is increased from q to $q+1$ the total cost will increase as of c_o . Similarly, in case $x \geq q+1$, put another way, in cases where the demand quantity is more than the order quantity, if the order quantity is increased one unit, the inventory that is not on hand will decrease one unit. This decrease will be as of c_u , the cost of understock per unit. c_u is defined as the cost of understock per unit.

By marginal analysis, the smallest value of q can be determined for which $E(q+1) - E(q) \geq 0$. To calculate $E(q+1) - E(q)$, we must consider two possibilities:

- $x \leq q$
- $x \geq q+1$

In summary, a fraction $P(X \leq q)$ of the time, ordering $q+1$ units will cost c_o more than ordering q units; and a fraction $1 - P(X \leq q)$ of the time, ordering $q+1$ units will cost c_u less than ordering q units. Thus, on the average, ordering $q+1$ units will cost

$$c_o P(X \leq q) - c_u [1 - P(X \leq q)]$$

more than ordering q units. Then $E(q+1) - E(q) \geq 0$ will hold if

$$P(X \leq q) \geq \frac{c_u}{c_o + c_u} \quad (2.3)$$

If we say $F(q) = P(X \leq q)$ the demand distribution function, then the optimal order quantity can be obtained from (2.4)

$$F(q^*) \geq \frac{c_u}{c_o + c_u} \quad (2.4)$$

For further information, see, Winston (2004).

2.2.1.2 Continuous Demand Case

Here the demand (X) is a continuous random variable and has the density function $f(x)$. The optimum order quantity q^* that would minimise the expected cost or maximise the expected profit may be calculated by setting the first derivative of the cost (profit) function to zero since it is convex (concave). The expected cost function

$$EC(q) = c_o \int_0^q (q-x)f(x)dx + c_u \int_q^\infty (x-q)f(x)dx \quad (2.5)$$

is minimized by ordering q^* units, where q^* is the smallest number satisfying

$$P(X \leq q^*) \geq \frac{c_u}{c_o + c_u} \quad (2.6)$$

Since demand is a continuous random variable, we can find a number q^* for which the inequality (2.6) holds with equality. Hence, in this case, the optimal order quantity can be determined by finding the value of q^* satisfying

$$P(X \leq q^*) = \frac{c_u}{c_o + c_u} \quad \text{or} \quad P(X \geq q^*) = \frac{c_o}{c_o + c_u} \quad (2.7)$$

(Winston, 2004)

On the other hand, if we are to consider profit instead of cost, and to express the profit as $\Pi(q)$ as a function of the order quantity q , the realised profit would be:

$$\Pi(q) = \begin{cases} rx + v(q - x) - cq, & \Rightarrow x \leq q \\ rq - b(x - q) - cq, & \Rightarrow x > q \end{cases} \quad (2.8)$$

Here, r represents the unit revenue, ($r > 0$); c represents the unit purchase cost, ($c > 0$); b represents the unit shortage cost, ($b > 0$) and v represents the unit salvage value, $v \in (-\infty, \infty)$. $v < c < r$ condition is valid as the standard assumption.

If the expected value of the realised profit is taken and the necessary simplifications are made, the widely known single period expected profit function $EP(q)$ is obtained.

$$EP(q) \equiv E[\Pi(q)] = (r - v)\mu + (v - c)q - (r + b - v) \int_q^{\infty} (x - q)f(x)dx, \quad (2.9)$$

where $\mu = E(X)$ is the expected demand during the period.

Differentiating $EP(q)$, equating $EP'(q)$ to zero and solving for q gives the necessary condition

$$1 - F(q) = \frac{c - v}{r + b - v} \quad (2.10)$$

and this leads to

$$q^* = F^{-1}\left(1 - \frac{c - v}{r + b - v}\right) \quad (2.11)$$

If the demand distribution is known, the optimal order quantity may be obtained from (2.11) using the distribution function.

2.2.2 The Satisficing/Aspiration-Level Model

In these types of models the purpose is to maximise the probability of exceeding the target profit. As it is mentioned in the previous chapter, Parlar & Weng (2002) emphasised that it is more advisable to maximise the probability of exceeding the expected profit on grounds that it may not always be possible determine a target profit. In this study, the aspiration-level model will be investigated in terms of the expected profit approach of Parlar & Weng (2002).

Borrowing a term used in reliability theory, Parlar & Weng (2002) call this the survivor probability; since it measures the likelihood of exceeding the expected profit level $EP(q)$, and denote it by $S(q) = \Pr[\Pi(q) \geq EP(q)]$.

$$S(q) = \Pr[\Pi(q) \geq EP(q)] = \Pr[x_1(q) \leq X \leq x_2(q)]$$

$$S(q) = \int_{x_1(q)}^{x_2(q)} f(x)dx, \quad (2.12)$$

where the limits $x_1(q)$ and $x_2(q)$ are obtained as functions of the order quantity q . This follows because the realized value of the profit exceeds expected profit $EP(q)$ if and only if the realized demand is between the lower and upper limits $x_1(q)$ and $x_2(q)$ (Parlar & Weng, 2002).

When the $S(q)$ function is examined, it is seen that $x_1(q)$ and $x_2(q)$ limits should be analysed accurately in its calculation. Therefore, it would be appropriate to evaluate $x_1(q)$ and $x_2(q)$ separately.

The relation between the expected profit function $EP(q)$ and $x_1(q)$ is

$$EP(q) = rx_1(q) + v[q - x_1(q)] - cq \quad (2.13)$$

(Parlar & Weng, 2002). It is observed that $x_1(q)$ is

$$x_1(q) = \max(0, \frac{EP(q) + (c - v)q}{r - v}) \quad (2.14)$$

considering it should be Non-negative. Put another way,

$$x_1(q) = \max(0, \xi(q)) \quad (2.15)$$

where

$$\xi(q) = \frac{EP(q) + (c - v)q}{r - v} \quad (2.16)$$

If $\xi(q)$ is rewritten using the expected profit function expansion,

$$\xi(q) = \mu - (1 + \frac{b}{r - v}) \int_q^\infty (x - q) f(x) dx \quad (2.17)$$

is obtained. Also,

$$\xi(0) = -\frac{b\mu}{r - v} < 0, \quad (2.18)$$

$$\xi'(q) = (1 + \frac{b}{r - v})[1 - F(q)] > 0, \quad (2.19)$$

$$\xi''(q) = -(1 + \frac{b}{r - v})f(q) < 0, \quad (2.20)$$

$$\lim_{q \rightarrow \infty} \xi(q) = \mu. \quad (2.21)$$

As it is understood from above, $\xi(q)$ function begins with a negative value at $q = 0$, and $\xi(q)$ function approaches to the average demand value as q approaches to infinity. In other words, $x_1(q)$ function cannot be greater than the average demand regardless of the expected profit level. Besides, it can be said that $x_1(q)$ is a concave function since its second derivative is smaller than zero.

$x_2(q)$ function from the relation with the expected profit function is obtained as

$$x_2(q) = \frac{(r+b-c)q - EP(q)}{b} \quad (2.22)$$

(Parlar & Weng, 2002).

$$x_2(0) = -\frac{EP(0)}{b} = \mu, \quad (2.23)$$

$$x_2'(q) = (1 + \frac{r-v}{b})F(q) > 0, \quad (2.24)$$

$$x_2''(q) = (1 + \frac{r-v}{b})f(q) > 0, \quad (2.25)$$

$$\lim_{q \rightarrow \infty} x_2(q) = +\infty. \quad (2.26)$$

As it is understood from above, $x_2(q)$ function begins from the average demand and approaches to infinite as q approaches to infinity. Also, it is a convex function as the second derivative is greater than zero.

After $x_1(q)$ and $x_2(q)$ values are calculated for a demand data for different order quantities, it would not be difficult to calculate $S(q)$ values for different order quantities. When the order quantity is defined as q_s^* in which the $S(q)$ probability is maximised among different order quantities, and when the order quantity that maximises the expected profit function is represented as q_p^* , a q_s^* value is obtained as of $q_s^* < q_p^*$. For further information and proofs, see, Parlar & Weng (2002).

2.2.3 The Newsvendor Model For Resalable Returns

The Newsvendor model can be applicable to the return goods. Accordingly, the return of the sold goods by the customers is in question. Differences may occur in the expected profit function or in demand depending on the returned goods being resalable or not. According to the classical model, the demand variable that can be named as gross demand may be considered as the net demand when it comes to the

resalable returns. Here, net demand N denote the total number of (gross) demanded products that are either not returned or returned but not resalable. The other concepts that would be used in this model are “the probability of a sold good to be returned” and “the probability of a returned good to be resold”. First, it would be helpful to define the variables that will be used in the model:

G : gross demand

m : expected probability that a sold product is returned

k : expected probability that a returned product is resalable

K : number of resalable returns if all demands are met

N : net demand, $N = G - K$

f_N : density function of net demand

F_N : distribution function of net demand

μ_N : mean of net demand

σ_N : standard deviation of net demand

p : selling price

b_N : net shortage cost

d : return collection cost

p_G : expected gross revenue

p_N : expected net revenue

q_p^* : optimal order quantity

As it is in the classical newsvendor model, here the purpose is to determine the order quantity that maximises the expected profit. The expected gross revenue may be written as

$$p_G = (1 - m)p - md + m(1 - k)v \quad (2.27)$$

paying regard to return and resale probabilities. As for expected net revenue, from the expected gross revenue point may obtained as,

$$p_N = (1 + mk + (mk)^2 + \dots)p_G = p_G / (1 - mk) \quad (2.28)$$

Similarly net shortage cost may be expressed as

$$b_N = b/(1 - mk) \quad (2.29)$$

(Mostard & Teunter, 2004).

The basic factors for the model to be implemented for the resalable returns are the expected net revenues and the net shortage costs. In the light of these information, with the assumption that the demand is continuous, the expected profit function is obtained as

$$\begin{aligned} EP(q) &= p_N(\mu_N - ES_N(q)) - cq - b_N ES_N(q) + v(q - (\mu_N - ES_N(q))) \\ EP(q) &= (p_N - v)\mu_N - (c - v)q - (p_N - v + b_N)ES_N(q) \end{aligned} \quad (2.30)$$

Here $ES_N(q)$ represents the expected number of unsatisfied net demands.

$$\begin{aligned} ES_N(q) &= E[N - q]^+ = \int_q^{\infty} (x - q)f_N(x)dx \\ &= \int_q^{\infty} xf_N(x)dx - q \int_q^{\infty} f_N(x)dx \\ &= \int_q^{\infty} xf_N(x)dx - q[1 - F_N(q)] \end{aligned} \quad (2.31)$$

To find the order quantity that maximises the expected profit function, the partial derivative of the function according to q should be calculated and it should be equalised to zero. If the partial derivative of $ES_N(q)$ with respect to q is calculated before this step

$$\begin{aligned} \frac{dES_N(q)}{dq} &= 0 - [1 - F_N(q)] \\ &= F_N(q) - 1 \end{aligned} \quad (2.32)$$

is obtained.

Then, by setting the partial derivative of $EP(q)$ with respect to q to zero,

$$\frac{dEP(q)}{dq} = -(c - v) - (p_N - v + b_N)[F_N(q) - 1] = 0 \quad (2.33)$$

$$F_N(q) = 1 - \frac{c - v}{p_N - v + b_N} \quad (2.34)$$

is obtained. From this, the optimal order quantity is obtained as

$$q_p^* = F_N^{-1} \left(1 - \frac{c - v}{p_N - v + b_N} \right) \quad (2.35)$$

2.2.4 Balancing Two Optimal Order Quantities

As the order quantity that maximises the expected profit function is symbolised as q_p^* , and as the order quantity that maximises the probability of exceeding the expected profit is symbolised as q_s^* , it is seen that different optimal order quantities are obtained for two different objectives. In this section, the optimal order quantity that optimises both of the objectives will be examined.

Using a single objective optimisation theory for a problem aiming at optimising two contradicting purposes will not produce any reasonable result. Therefore, using *the vector optimization problem (VOP)* would be more appropriate as Parlar & Weng (2002) cite. According to VOP, the problem is represented as (EP^*, S^*) . For the current problem, one needs to develop a procedure for generating the set of points in the EP/S-plane that are not inferior to any other points (Parlar & Weng, 2002).

The most ideal point, among the derived set of points, will be the solution of both the VOP and the problem including the two objectives. There are various methods in finding solution to VOP. According to the most common method, the “nearest” point to the (EP^*, S^*) , which is the most ideal point in the non-inferior solution set, is the solution. Accordingly,

$$\min_{q \geq 0} L_p(EP(q), S(q)) = \{ w \left[\frac{EP^* - EP(q)}{EP^*} \right]^p + (1 - w) \left[\frac{S^* - S(q)}{S^*} \right]^p \}^{1/p} \quad (2.36)$$

for $1 \leq p \leq \infty$ and $0 \leq w \leq 1$ (Zeleny, 1982).

According to the theorem stated in Parlar & Weng (2002), when $S(q)$ is a unimodal function with a unique maximizer, the solution q^* that minimizes the L_p function assumes a value between q_s^* and q_p^* .

Then, the value will correspond to the value q^* which is the minimum value of the L_p that corresponds to the different order quantities that can be obtained from (2.36) and will be between q_s^* and q_p^* values.

CHAPTER THREE

APPLICATION

3.1 Introduction

In this chapter, the methods explained in the previous chapters regarding the aims of this study will be applied on the simulated data. Before explaining the advantages and the disadvantages of using real and derived data, it would be appropriate to state the assumptions concerning the problem.

The primary assumption concerning the model is that the customer demands follow to the normal distribution with mean μ and variance σ^2 . In this model, optimisation for a single product is searched and the probability rate of return for each product is the same. For the returned goods to be resalable, they should be returned before the end of the season and their condition, whether they are resalable or not, should be determined. As the return probability, the probability of the goods being resalable is constant. The goods may be resold for many times. Another assumption is, as it is mentioned in the previous chapter, the condition $v < c < r$.

There are several reasons for using simulated data instead of real data. The very first and the most important one is that the resalable return system is not common enough in our country and the databases of the enterprises that have this system are inappropriate.

It is obvious that real data, obtained in the correct way and according to the purpose, would avail both in modelling and the use of the model in estimation. However, there may be some disadvantages of using real data. In studies with limiting assumptions, for instance, it is rarely seen that an assumption relating to distribution is provided for real data.

3.2 Data

The first step in determining the order quantity range to be used in the application is to analyse the data related to the demand variable. With this design, 10000 demand data were simulated from normal distribution with mean 400 and standard deviation 20. The descriptive statistics concerning the demand data is given in Table 3.1. According to Table 3.1, the data concerning the demand variable show variance between 327.10 minimum and 470.73 maximum values with a mean 399.95 and a standard deviation 19.99. The histogram of the demand data is presented in Figure 3.1.

Table 3.1 Descriptive statistics of demand variable

Variable	X
N	10000
N*	0
Mean	399.95
SE Mean	0.200
StDev	19.99
Minimum	327.10
Q1	386.49
Median	399.92
Q3	413.11
Maximum	470.73

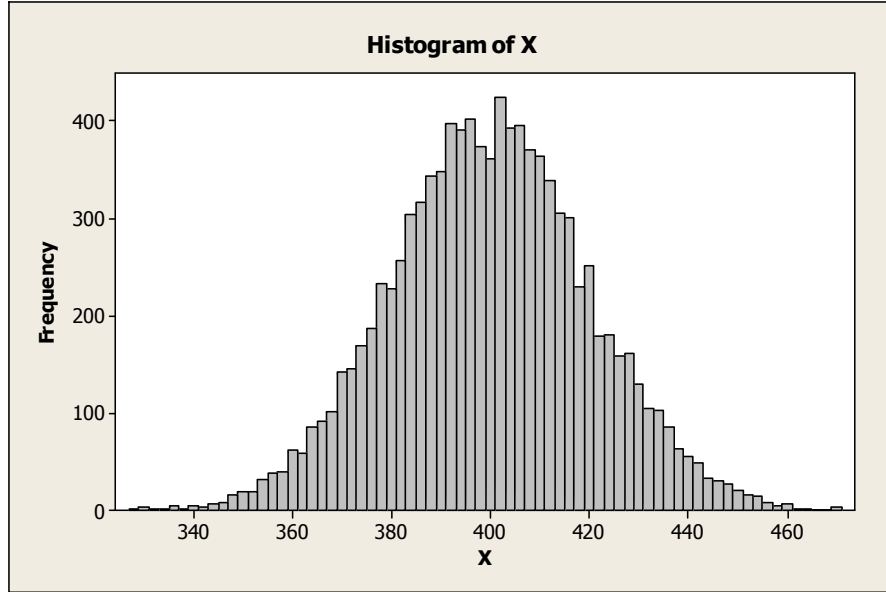


Figure 3.1 Histogram of demand variable

Values are assigned, in accordance with the assumptions, to the other parameters to be known in determining the optimum order quantity. Accordingly, unit revenue, $r = 30$ TL; unit purchase cost, $c = 25$ TL; unit shortage cost, $b = 60$ TL and the salvage value, $v = 19$ TL will be used as given. In the calculations for resalable returns, the probability of return, $m = 0.50$; probability for the returns being resalable, $k = 0.95$; selling price, $p = 50$ TL; return collection cost, $d = 5$ TL will be used as given.

3.3 Analysis of Non-Resalable Products

The main aim in the study being the application of the newsvendor model using the aforementioned methods for the resalable return goods, however, performing applications for the goods without return would also be useful in terms of comparison.

The order quantity range is determined as $[300, 491]$ considering the minimum and maximum values of the demand. Since the purpose is profit maximisation in the classical newsvendor model, the profit function should be determined first. The profit function explained in (2.9), was calculated iteratively for the corresponding order

quantities and the order quantity in which the greatest profit obtained was accepted as the optimum order quantity for the classical newsvendor model.

$$\max(EP(q)) = 1779.93$$

The derivation of the optimum order quantity using the order quantity distribution function mentioned in (2.10) is given below.

$$F(q) = 1 - \frac{25 - 19}{30 + 60 - 19} = 0.915493$$

$$q_p^* = F^{-1}(0.915493) \cong 428$$

$$EP(428) = 1779.93$$

Accordingly, the optimal order quantity for the classical newsvendor model is 428 units and the profit to be earned is 1779.93 TL. In other words, if the decision maker orders 428 unit before the season, he would earn 1779.93 TL profit at the end of the season.

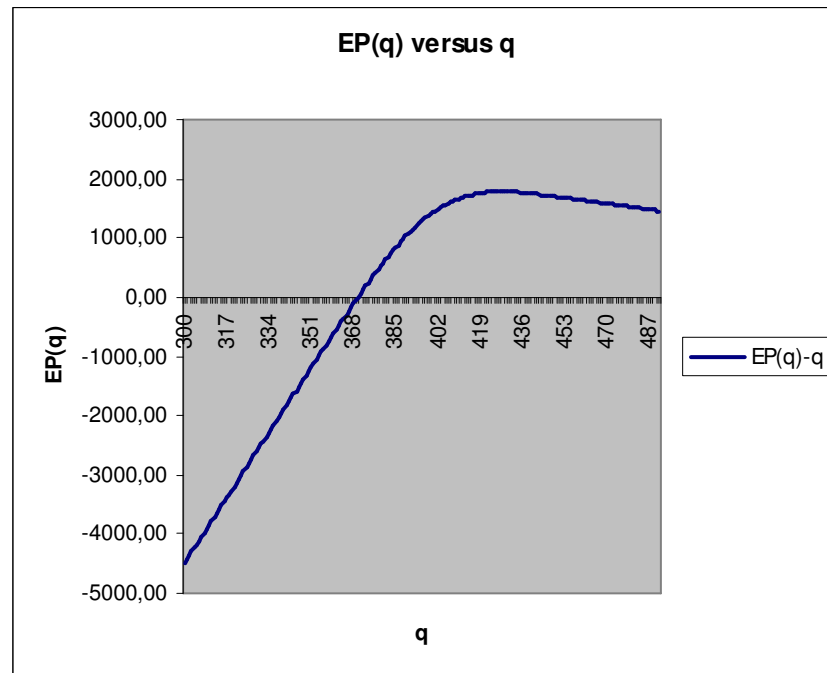
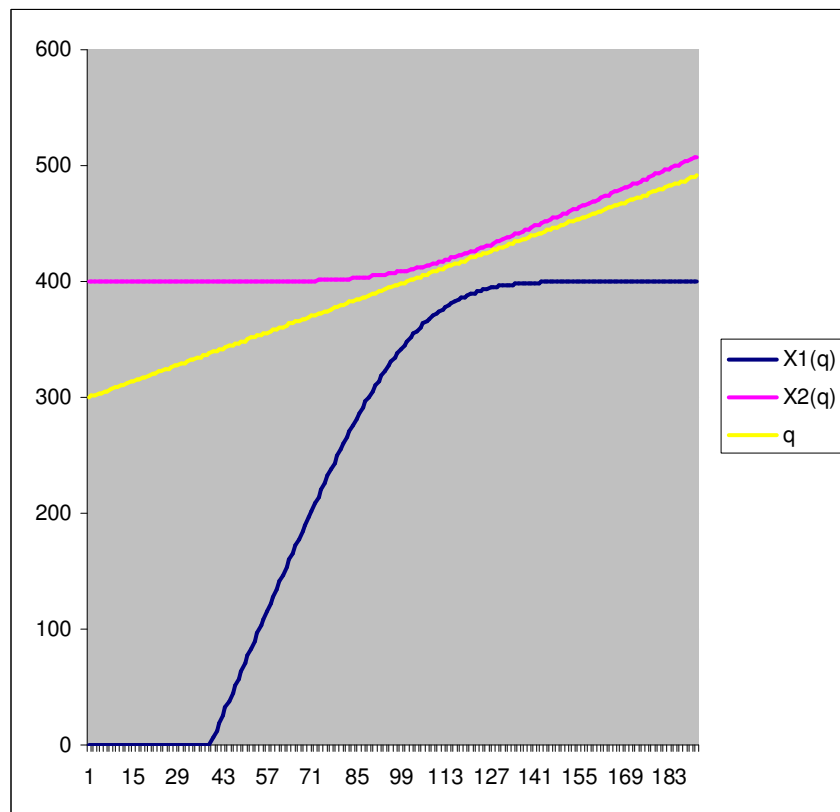
The relationship between the profit function and order quantities can be seen in Figure 3.2.

In finding the optimal order quantity that maximises the probability of exceeding the expected profit $S(q)$, firstly $x_1(q)$ and $x_2(q)$ should be calculated. According to $x_1(q)$ and $x_2(q)$ functions given in (2.14) and (2.22),

$$x_1(q) = \max(0, \frac{EP(q) + (25 - 19)q}{30 - 19})$$

$$x_2(q) = \frac{(30 + 60 - 25)q - EP(q)}{60}$$

Both functions are calculated iteratively for different order quantities. The relationship between $x_1(q)$, $x_2(q)$ and order quantity is presented in Figure 3.3.

Figure 3.2 $EP(q)$ versus q Figure 3.3 Relations between $x_1(q)$, $x_2(q)$ and q

The $S(q)$ function in (2.12), is calculates for all order quantities using $x_1(q)$ and $x_2(q)$ and the point where the $S(q)$ function is at maximum becomes the point where the probability of exceeding the expected profit is the highest.

$$S(q) = \int_{x_1(q)}^{x_2(q)} f(x) dx$$

is

$$\max(S(q)) = 0.70623$$

and the expected profit will be exceeded at a probability rate of 0.70623 in the corresponding order quantity value.

The order quantity where the greatest $S(q)$ value is obtained is the optimum order quantity and it corresponds to 406. Accordingly, in order to maximise the probability of exceeding the expected profit, 406 units should be ordered.

$$q_s^* = 406$$

The relationship between $S(q)$ and order quantities are given in Figure 3.4.

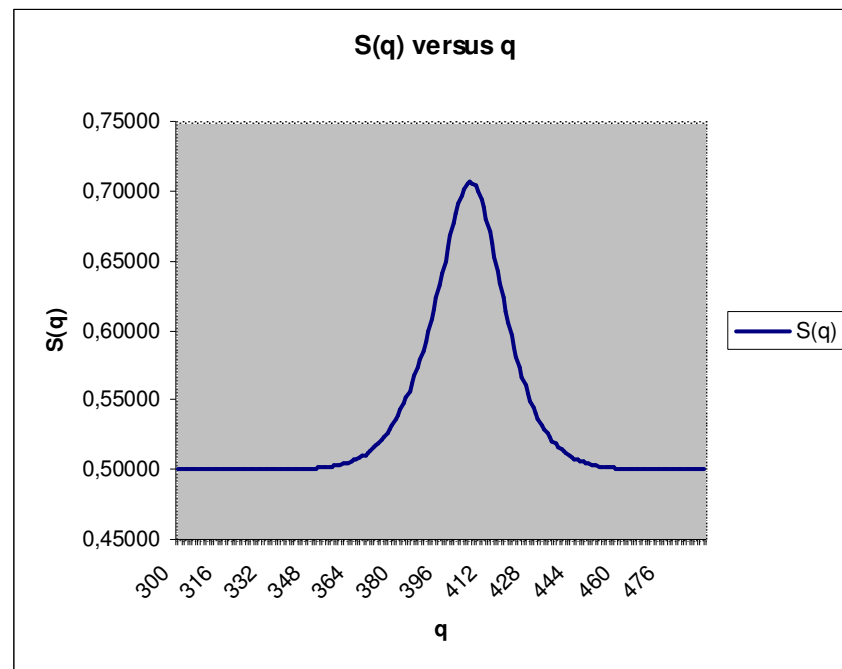


Figure 3.4 $S(q)$ versus q

When the probability of exceeding the expected profit is calculated for the value $q_p^* = 428$,

$$S(428) = 0.54899$$

is obtained. From this perspective, it is seen that the calculated order quantity value for the classical newsvendor model is inadequate in maximising the probability of exceeding the expected profit.

In order to determine the order quantity that would optimise both the profit function and the probability of exceeding the expected profit together, the function $L(EP(q), S(q))$ in (2.36) was used. The function was used iteratively and the order quantity corresponding to the value where the distance between two purposes had the minimum value was determined as the optimum order quantity.

$$\min_{q \geq 0} L_p(EP(q), S(q)) = \{w[\frac{EP^* - EP(q)}{EP^*}]^p + (1-w)[\frac{S^* - S(q)}{S^*}]^p\}^{1/p}$$

In L function weight (w) is taken as 0.4, a value of 2 is used for p value representing the *Euclid* distance. Accordingly,

$$\begin{aligned} \min_{q \geq 0} L_2(EP(q), S(q)) &= \{0.4[\frac{1779.93 - EP(q)}{1779.93}]^2 + (1-0.4)[\frac{0.70623 - S(q)}{0.70623}]^2\}^{1/2} \\ &= 0.04246 \end{aligned}$$

is obtained. The corresponding order quantity is the optimum order quantity and it is 411 units.

$$q^* = 411$$

$EP(q)$ and $S(q)$ values for q_p^* , q_s^* and q^* order quantities are presented in Table 3.2. Accordingly, it is easily understood that order quantity q^* is a quantity that balances the values q_p^* and q_s^* which optimise other two objectives.

Table 3.2 Comparison of optimal order quantities for non-resalable

q	$EP(q)$	$S(q)$
406	1585.20	0.70623
411	1674.42	0.68806
428	1779.93	0.54899

Tables for different r , c , v and b values are presented below.

Table 3.3 Sensitivity analysis for r

r	q_p^*	q_s^*	$1 - \frac{S(q_p^*)}{S(q_s^*)}(\%)$	$1 - \frac{EP(q_s^*)}{EP(q_p^*)}(\%)$	q^*	$L_2(q^*)$
26	427	411	21.41	51.40	420	0.09614
30	428	406	22.27	10.94	411	0.04246
34	428	403	20.49	8.52	408	0.03617
38	429	401	18.91	7.47	406	0.03357
42	429	399	17.00	7.15	404	0.03207

Table 3.4 Sensitivity analysis for c

c	q_p^*	q_s^*	$1 - \frac{S(q_p^*)}{S(q_s^*)}(\%)$	$1 - \frac{EP(q_s^*)}{EP(q_p^*)}(\%)$	q^*	$L_2(q^*)$
21	438	406	26.86	8.53	411	0.03961
23	432	406	24.64	9.16	411	0.03956
25	428	406	22.27	10.94	411	0.04246
27	424	406	18.90	16.71	412	0.05195
29	422	406	16.78	147.00	418	0.09917

Table 3.5 Sensitivity analysis for v

v	q_p^*	q_s^*	$1 - \frac{S(q_p^*)}{S(q_s^*)}(\%)$	$1 - \frac{EP(q_s^*)}{EP(q_p^*)}(\%)$	q^*	$L_2(q^*)$
15	422	403	16.69	11.91	409	0.04080
17	425	405	19.45	10.67	410	0.04163
19	428	406	22.27	10.94	411	0.04246
21	431	408	25.13	10.32	413	0.04292
23	438	411	30.21	9.23	415	0.04355

Table 3.6 Sensitivity analysis for b

b	q_p^*	q_s^*	$1 - \frac{S(q_p^*)}{S(q_s^*)}(\%)$	$1 - \frac{EP(q_s^*)}{EP(q_p^*)}(\%)$	q^*	$L_2(q^*)$
20	417	396	8.74	6.56	402	0.02412
40	424	402	17.66	9.38	408	0.03621
60	428	406	22.27	10.94	411	0.04246
80	430	409	24.65	11.86	414	0.04684

In Table 3.3 q_p^* , q_s^* , q^* order quantities, L_2 distance function values, $1 - S(q_p^*)/S(q_s^*)$ and $1 - EP(q_s^*)/EP(q_p^*)$ percentage values for different r values are presented. Accordingly; it is seen that as r increases q_p^* increases too, but q_s^* and q^* decreases. In other words, the increase in revenue per unit, in the classical newsvendor model, requires placing more orders to maximise the profit and requires placing fewer orders to maximise the probability of exceeding the expected profit. The percentage values for S and EP functions express the loss. If the enterprise places an order quantity q_p^* orders instead of q_s^* , it would face decreasing loss percentages in probability objective for increasing r values. Similarly, if it places an order quantity q_s^* instead of q_p^* for EP function it would face a decreasing loss percentage for increasing r values. The inferences corresponding to the changing c , v and b values should be done accordingly. The order quantity q^* that balances these two models showed changes parallel to q_s^* . It can be said that as the unit purchase cost c increases q_p^* decreases, q_s^* remains constant, and q^* is in a tendency to increase as the difference between q_p^* and q_s^* increases. However, it is obvious that this increase would be fixed at a particular point since q^* would get a value between other two order quantities. In Table 3.5, it is seen that as the salvage value v increases, all three order quantities increase. Similarly in Table 3.6, it is seen that as the shortage cost b increases all three order quantities increase, thus as the understock cost increases there will be occur a requirement to have more quantities of goods.

3.4 Analysis of Resalable Products

When the analyses mentioned in the previous chapters were conducted for the resalable returns, results obtained were parallel to results of the analyses conducted for the non-resalable goods.

In order to find the order quantity that maximises profit, which is the classical purpose, the profit function in (2.30) should be obtained for each order quantity, and then the point where it is at maximum should be determined.

As the expected profit function for this model is,

$EP(q) = p_N(\mu_N - ES_N(q)) - cq - b_N ES_N(q) + v(q - (\mu_N - ES_N(q)))$, p_N and b_N values should be calculated. The expected gross revenue is obtained as below using the parameters defined before,

$$\begin{aligned} p_G &= (1 - m)p - md + m(1 - k)v \\ p_G &= (1 - 0.50)50 - 0.50 * 5 + 0.50(1 - 0.95)19 \\ &= 22.98 \end{aligned}$$

Expected net revenue,

$$\begin{aligned} p_N &= (1 + mk + (mk)^2 + \dots)p_G = p_G / (1 - mk) \\ p_N &= 22.98 / (1 - 0.50 * 0.95) \\ &= 43.76 \end{aligned}$$

is obtained as above. Net shortage cost is found as,

$$\begin{aligned} b_N &= b / (1 - mk) \\ b_N &= 60 / (1 - 0.50 * 0.95) \\ &= 114.2857 \end{aligned}$$

It is possible to calculate the optimal order quantity for non-resalable goods similarly, using the $F_N(q)$ function in (2.34).

$$\begin{aligned} F_N(q) &= 1 - \frac{25 - 19}{43.76 - 19 + 114.2857} \\ &= 0.96 \end{aligned}$$

$$q_p^* = F_N^{-1}(0.96) \\ \cong 434$$

Since

$$EP(434) = 43.76(400 - ES_N(434)) - 25 * 434 - 114.2857ES_N(434) \\ + 19(434 - (400 - ES_N(434)))$$

first $ES_N(434)$ should be calculated. From the function in (2.31),

$$ES_N(434) = 0.365756$$

is obtained. Accordingly,

$$EP(434) = 7249.90 \text{ TL}$$

is obtained.

By using p_N and b_N values obtained and the parameter values defined before, $EP(q)$ values can be also calculated for different order quantities successively. The order quantity that corresponds to the greatest $EP(q)$ value would be the optimal order quantity for classical model. The relationship between the profit function and order quantity is presented in Figure 3.5.

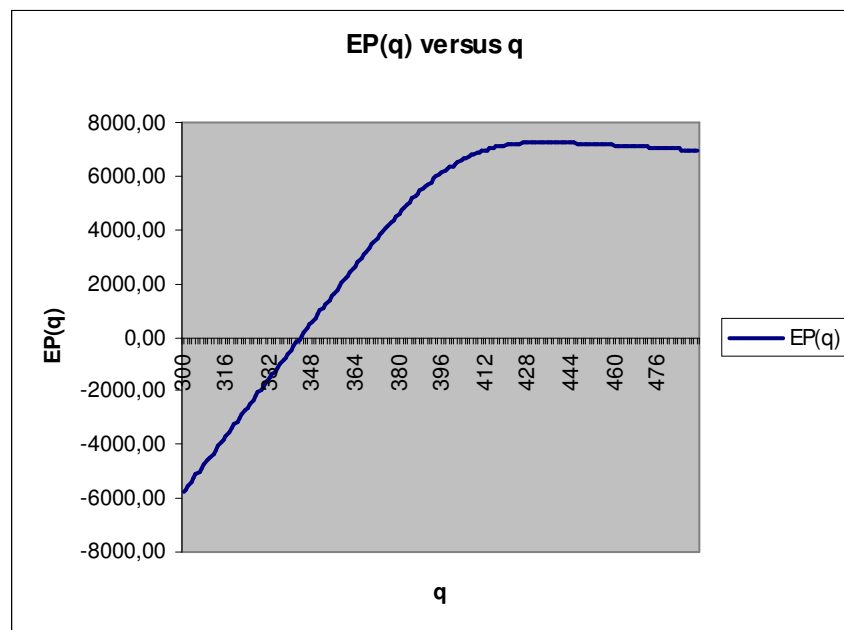


Figure 3.5 $EP(q)$ versus q

As a result, if the decision maker orders 434 units of products before the season, he would earn 7249.90 TL profit at the end of the season.

In order to obtain the order quantity that maximises the probability of exceeding the expected profit $S(q)$, again $x_1(q)$ and $x_2(q)$ limits should be calculated first.

$$x_1(q) = \max\left(0, \frac{EP(q) + (25 - 19)q}{43.76 - 19}\right)$$

$$x_2(q) = \frac{(43.76 + 114.2857 - 25)q - EP(q)}{114.2857}$$

$x_1(q)$ and $x_2(q)$ limits are calculated for different q values. Similar to the ones in non-resalable goods, the relationship between $x_1(q)$, $x_2(q)$ and the order quantity is presented in Figure 3.6.

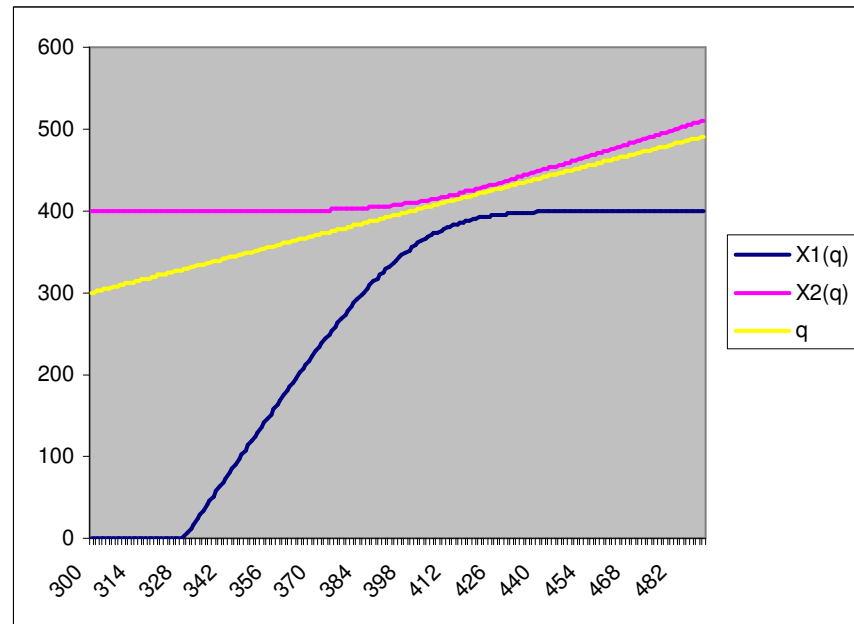
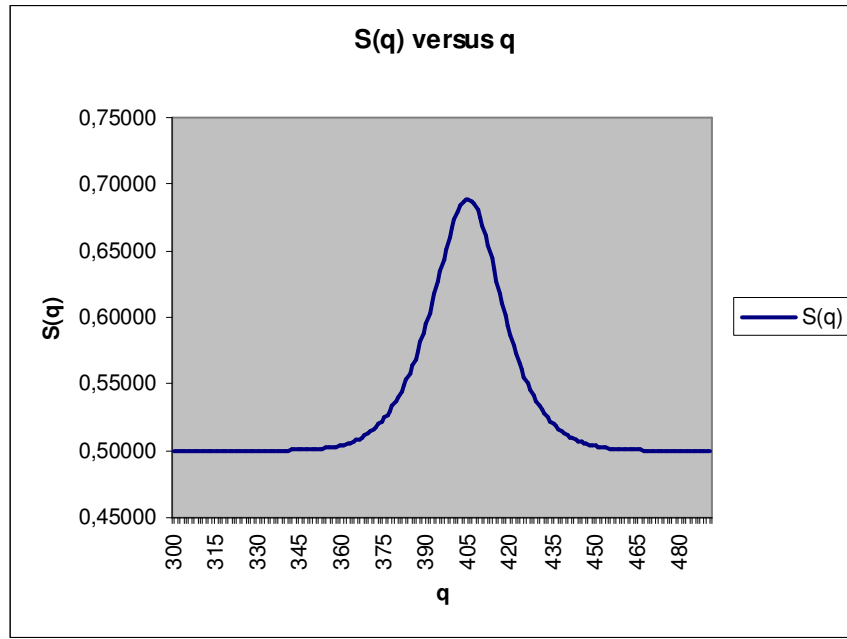


Figure 3.6 Relations among $x_1(q)$, $x_2(q)$ and q

After the $x_1(q)$ and $x_2(q)$ limits are obtained, $S(q)$ probabilities can be calculated for all possible order quantities. The order quantity that corresponds to $S(q)$ at maximum, again would be the optimal order quantity. Figure 3.7 presents the relationship between $S(q)$ and q .

Figure 3.7 $S(q)$ versus q

$\max(S(q)) = 0.68905$ thus, the expected profit will be exceeded with a 0.68905 probability for the corresponding order quantity.

The order quantity where the greatest $S(q)$ value is obtained, is the optimum order quantity and it corresponds to 405. Accordingly, in order to maximise the probability of exceeding the expected profit, 405 units should be ordered.

$$q_s^* = 405$$

In order to determine the order quantity that maximises both the profit function and the probability of exceeding the expected profit together, again $L(EP(q), S(q))$ function in (2.36) was used. w and p values are taken as 0.40 and 2. L function value obtained is,

$$\min_{q \geq 0} L_2(EP(q), S(q)) = 0.03768$$

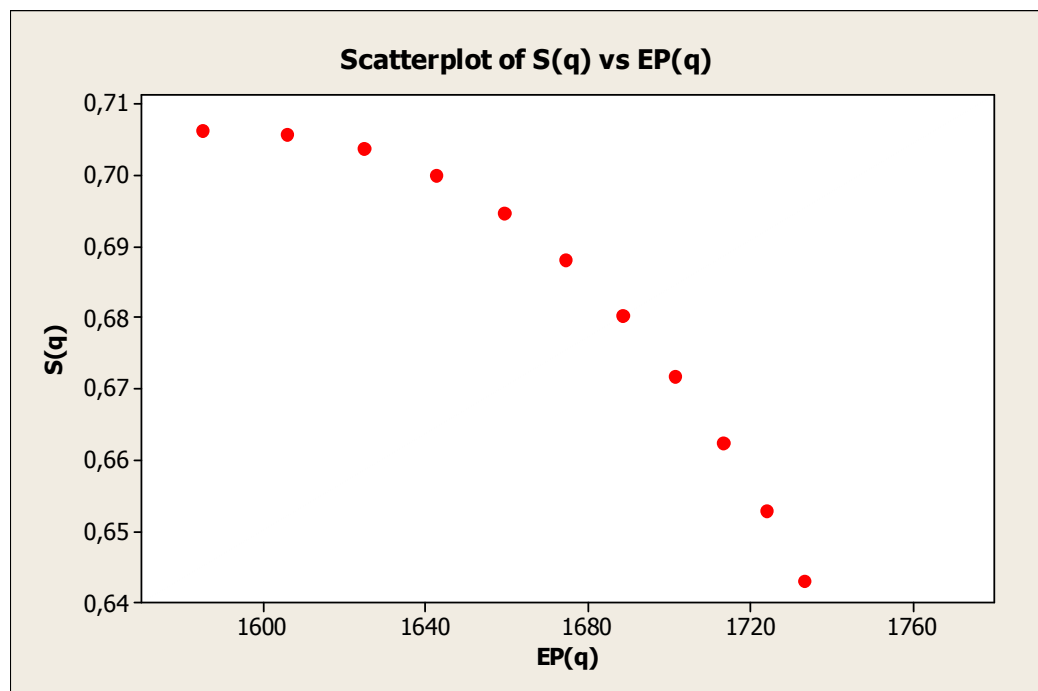
and the corresponding order quantity value is found as $q^* = 409$.

Table 3.7 presents $EP(q)$ and $S(q)$ values for order quantities q_p^* , q_s^* and q^* .

Table 3.7 Comparison of the optimal order quantities for resalable

q	$EP(q)$	$S(q)$
405	6678.45	0.68905
409	6856.56	0.67520
434	7249.90	0.52261

The scatter-plot that summarises the study is presented in Figure 3.8.

Figure 3.8 Scatterplot of $S(q)$ versus $EP(q)$

It is understood from Figure 3.8 that, it is possible to achieve the solution that optimises the two purpose functions with a value between the order quantities that maximises $S(q)$ and $EP(q)$. As the expected profit increases, the probability of exceeding this profit decreases. Depending on the weight value w in the L distance function, the position of (EP^*, S^*) can be estimated.

As the parameters which bear importance for resalable returns are “probability of the returns being resalable” k and “probability of return” m , the optimal order quantities obtained for different k and m values are presented in the tables below.

Table 3.8 Sensitivity for k

k	q_p^*	q_s^*	q^*
0.25	429	405	409
0.50	431	405	409
0.75	433	405	409
0.95	434	405	409

Table 3.9 Sensitivity for m

m	q_p^*	q_s^*	q^*
0.25	432	399	405
0.50	434	405	409
0.75	439	416	420

Table 3.8 presents q_p^* , q_s^* and q^* values for different k values. Accordingly, it is seen that as the probability of being resalable for the returns k increases, q_p^* has a tendency to increase, and q_s^* and q^* remains unaffected. In Table 3.9, it is seen that as the probability of return m increases, all three order quantities increase. The reason for this is that revenue per unit decreases when the probability of return increases and thus the enterprise would be in a tendency to place more orders in order to increase profitability. Also, placing more orders will prevent the enterprise to pay more for the net shortage cost.

In addition to the probability of return and probability of returns being resalable, sensitivity analyses were conducted for c , v and b_N values and the result presented in the table below were obtained. In obtaining different b_N values the $b_N = b/(1 - mk)$ function was used and for b parameter 20, 40, 60, 80 values are used respectively.

Table 3.10 Sensitivity analysis for net shortage cost

b_N	q_p^*	q_s^*	$1 - \frac{S(q_p^*)}{S(q_s^*)}(\%)$	$1 - \frac{EP(q_s^*)}{EP(q_p^*)}(\%)$	q^*	$L_2(q^*)$
38.095	426	395	10.458	5.911	402	0.02452
76.19	431	401	19.336	7.202	406	0.03389
114.286	434	405	24.155	7.882	409	0.03768
152.381	437	407	27.549	9.043	412	0.04031

Table 3.11 Sensitivity analysis for c

c	q_p^*	q_s^*	$1 - \frac{S(q_p^*)}{S(q_s^*)}(\%)$	$1 - \frac{EP(q_s^*)}{EP(q_p^*)}(\%)$	q^*	$L_2(q^*)$
21	444	405	26.378	7.827	409	0.03911
23	438	405	25.301	7.801	409	0.03817
25	434	405	24.155	7.882	409	0.03768
27	432	405	23.405	8.077	409	0.03761
29	429	405	21.996	8.42	409	0.03803

Table 3.12 Sensitivity analysis for v

v	q_p^*	q_s^*	$1 - \frac{S(q_p^*)}{S(q_s^*)}(\%)$	$1 - \frac{EP(q_s^*)}{EP(q_p^*)}(\%)$	q^*	$L_2(q^*)$
15	430	403	21.416	8.298	408	0.03607
17	432	404	22.802	8.056	409	0.03707
19	434	405	24.155	7.882	409	0.03768
21	438	405	26.057	8.465	410	0.03874
23	444	406	28.063	8.454	411	0.04037

Table 3.13 Sensitivity analysis of L_2 for varying values of weight w

w	q_p^*	q_s^*	q^*	$L_2(q^*)$
0.0	434	405	405	0.00000
0.2	434	405	408	0.02891
0.4	434	405	409	0.03768
0.6	434	405	410	0.04230
0.8	434	405	412	0.04222
1.0	434	405	434	0.00000

Table 3.10 presents order quantities for different net shortage cost values, percentage of losses and minimum L function values. All three order quantities has the tendency to increase as the b_N value increases. The loss percentage would

increase in case opposite order quantities are used as optimal for S and EP function as b_N increases. In Table 3.11, it is seen that q_p^* decreases, and q_s^* remains unaffected since the profitability level for the unit purchase cost values would decrease. Some slight changes in the loss percentages are observed. In Table 3.12, it is seen that, as salvage value v increases, all three order quantities increase. The loss percentages for S and EP functions are as presented in the table.

In table 3.13 sensitivity analysis of L_2 function for the varying values of the weight w is presented. Taking other parameters with their defined values, weight w is increased by 0.2 units from zero to one. It is observed that for low values of w the optimal solution for the balanced problem approaches the solution for the probability maximization objective. For w approaches to 1, the solution of the problem approaches the solution for the expected profit maximization objective.

CHAPTER FOUR

CONCLUSION

The purpose of this study is to define order policy for resalable returned products by using the single period inventory model which is also known as newsvendor model. In the scope of the study, two different objective functions are observed. These are; maximising the expected profit and maximising the probability of exceeding the expected profit. These two objective functions are examined for non-returned products firstly, and then for resalable returns. Lastly, the order quantity that optimises these two conflicting objectives together is searched.

It is seen that as the probability of being resalable for the returns increases, the order quantity that maximises the expected profit has a tendency to increase, whereas, the order quantities for the other purposes hold constant. On the other hand as the probability of return increases, the order quantities for all purposes increase. The reason for this is that revenue per unit decreases when the probability of return increases and thus the enterprise would be in a tendency to place more orders in order to increase profitability.

All three order quantities have the tendency to increase as the shortage cost increases. The loss percentage would increase in case opposite order quantities are used as optimal for S and EP function as the shortage cost increases.

It is seen that the order quantity that maximises the expected profit decreases and the order quantity that maximises the probability of exceeding the expected profit remains unaffected since the profitability level for the unit purchase cost values would decrease. Some slight changes in the loss percentages are observed.

As salvage value v increases, all three order quantities increase. The loss percentages for S and EP functions increase as the salvage value increases.

According to the results of application, a similarity observed between the results of returns and non-returns. It can be said that, the loss percentages are bigger for returned products according to the results of sensitivity analyses.

In this study, the inventory policy is determined under the assumption of normality of the demand data. If the demand variable follows a different distribution, especially one of the non-symmetric distributions, new mathematical approaches will be needed. For future studies, the demand variable may be assumed to follow different distributions other than normal distribution.

Besides, in the scope of the study, the returned products are assumed to be sold many times. In real life situations returned products may not be sold many times. If this detail can be added, the model will be more applicable.

In summary, this study proved that the newsvendor model is applicable for many purposes and for resalable products. Competing enterprises can make use of this model for the purpose of maximising both the costumer satisfaction and their profit; and this makes them a step forward as well.

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