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AN ECONOMIC PRODUCTION QUANTITY MODEL WITH DEFECTIVE PRODUCTION[1]

KUSURLU ÜRETİMİN OLDUĞU BİR EKONOMİK ÜRETİM MİKTARI MODELİ

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ABSTRACT

The classic economic production quantity model is used to find the optimum production quantity. One of the main assumptions of this model is that all of the products produced during the planning period are perfect. However, this assumption is not always valid. The difficulty of managing a large number of variables affecting production systems may cause a certain amount of defective products. In this study, the economic production quantity (EPQ) model was proposed for a situation where the defective ratio of the products produced is classified as uniform and normal distribution and the defective products can be repaired, low quality and scrap, and numerical examples are given for the proposed model.

Keywords: *Economic Production Quantity, Defective Product, Rework.*

Jel Codes: *C61, M11*

ÖZ

Klasik ekonomik üretim miktarı modeli optimum üretim miktarının bulunması amacıyla kullanılmaktadır. Bu modelin temel varsayımlarından biri, planlama dönemi boyunca üretilen ürünlerin tamamının kusursuz olduğu biçimindedir. Ancak bu varsayım her zaman geçerli değildir. Üretim sistemlerini etkileyen çok sayıda değişkenin yönetilmesinin zorluğu, belirli miktarda kusurlu ürün üretilmesine sebep olabilir. Bu çalışmada, üretilen ürünlerin kusurlu oranının tekdüze ve normal dağılım gösterdiği, kusurlu ürünlerin tamir edilebilir, düşük kalite ve hurda olarak sınıflandırıldığı bir durum için ekonomik üretim miktarı modeli (EÜM) önerisi yapılmış ve önerilen model için sayısal örnek verilmiştir.

Anahtar Kelimeler: *Ekonomik Üretim Miktarı, Kusurlu Ürün, Yeniden İşleme.*

Jel Kodları: *C61, M11*

1. INTRODUCTION

[1] This study is derived from the second author's doctoral thesis in preparation.

Inventories are defined as the current assets of materials, semi-finished or finished products having an economic value that will either be used in production or sold in the future (Demir and Gumusoglu, 2003:619). Businesses need to have a sufficient amount of inventory to carry out their activities and to respond to customer demands and requirements on time. The fact that inventory costs account for a substantial percentage of operating costs leads business managers to seek answers to the questions "How frequently and in what quantity should be produced or ordered?" to minimize total costs and maximize total profits in the process of determining and controlling the inventory level (Aydemir, 2015:98) Classical inventory models are one of the many approaches developed to answer these questions. The basic assumptions of these models are that the demand rate is continuous and constant throughout the planning period, the quantity of demand is known with certainty and all units produced/ordered are of perfect quality (Eroğlu, 2002:7; Eroğlu et al., 2008:923). However, these models, in which the uncertainty is low and simplifying assumptions are accepted, are insufficient to meet the problems in industrial life. This has led researchers to develop models that address inflation and time value of money, learning effects, defective (imperfect) production, and degradation (deterioration) of some of the products held in stock, quality control, stock-outs, demand fulfillment, and changes in the demand rate. Since this study develops a model under the assumptions of imperfect production and rework, studies that take these assumptions into account are included in the following section of the study.

Schrady (1967) was the first to address the addition of rework and/or repair processes to deterministic inventory models in the literature (Aydemir, 2015:104). In the study, Schrady (1967) developed a deterministic inventory model for reworkable inventory systems and determined the optimal production and rework quantities. Rosenblatt and Lee (1986) examined the effects of imperfect (defective) production processes on the optimal production cycle time. It is hypothesized that the system breaks down during the production process and produces some defective products. The optimal production cycle time was found and it was shown that this time is shorter than the cycle time in the classical EPQ model. Hayek and Salameh (2001) studied the effect of defective products on the production model. They developed a new EPQ model under the assumptions that the percentage of defective products is a random variable and follows a known probability distribution, that defective products are reworked into defect-free products when production stops, and that stock-outs are not permitted. Chan et al. (2003) developed three EPQ models considering different situations and time factors. The study assumed that manufactured products are categorized as good, reworked to make them good, low quality, scrap, and that low-quality products are sold at discounted prices. The basic assumption that distinguishes the models from each other is that the sales times of low-quality products are different. Eroglu et al. (2008) extended the model developed by Chan et al. (2003) with the assumptions of allowing stock-outs and taking repair time into account. Sana (2010) developed an EPQ model with the assumption that the production process goes out of control and produces defective products and that the production rate of defective products is a non-linear function of both production rate and production time. Sarkar et al. (2014) developed three different EPQ models for a single-stage production system for the cases where rework, late fulfillment of demand is permitted and the defective rate, which is a random variable, obeys uniform, triangular and beta probability distributions. Liao (2016) examined the impact of repair and occasional preventive maintenance on a deteriorating production system. Numerical analysis in this study showed that increasing maintenance activities and production capacity increases product reliability, which in turn reduces production and warranty costs. Moussawi-Haidar et al. (2016) developed two different EPQ models for a single-stage production process that produces defective products at a random rate. In the study, they integrated the inspection time into the production model with rework. Öztürk (2017) showed that some mathematical expressions in the model developed by Moussawi-Haidar et al. (2016) for the remanufacturing process of defective products are not correct and obtained new optimum solutions for the numerical example in the study. Karagul (2021), developed two different EPQ models in which quality control, rework and stockout situations are also considered in production processes with imperfect production. The assumptions and functioning of the second model which Moussawi–Haidar et al. (2016) discussed in their article are discussed from a different perspective in this study. Also, classical economic order quantity and classical economic production quantity models were coded with SageMath software. Eroglu and Sahin (2023) proposed a fuzzy inventory model including the recycling process that can contribute to the maximum recovery and minimum waste strategy, which is the basis objective of the recycling industry.

In this study, the EPQ model under quality control and rework assumptions developed by Karagul (2021) is extended with the assumption of classification of defective products.

2. MATHEMATICAL MODEL

An EPQ model has been developed for a production system where a single item is produced in batches. Manufactured products contain a stochastic proportion p of defective products with probability density function f(p). Defective products are categorized as scrap, repairable and low-quality. The scrap products are removed from the inventory at a certain cost, low-quality products are sold wholesale, and repairable products are remanufactured into good products. Stockout is not permitted.

2.1. Deriving the Model

Notations used in the model

β : Demand rate (quantity demanded per unit time)

α : Production rate (production quantity per unit time)

α_1: Repair rate (amount of product repaired per unit time)

x : Inspection speed (amount of sorting (separation of defective and defective-free products) per unit time)

y : The quantity of production in the cycle

p : Percentage of the defective products (random variable)

δ_1: Percentage of repaired products among defective products

δ_2: Percentage of the scraps in defective products

δ_3: Percentage of the low-quality products in defective products ($\delta_1 + \delta_2 + \delta_3 = 1$)

c : Unit production cost

c_r : Unit repair cost

d : Unit inspection cost

m : Cost of removing unit scrap product from inventory

K : Production preparation cost

s : The unit selling price of the good product

v : The unit selling price of a low-quality product

h : Unit inventory cost

h_1: Unit stock cost for defective products

The changes in the inventory level during the cycle time of the developed EPQ model including defective product, inspection and rework situations are shown in Figure 1 and Figure 2.

Figure 1. EPQ Model for Defective Product, Inspection and Rework Cases

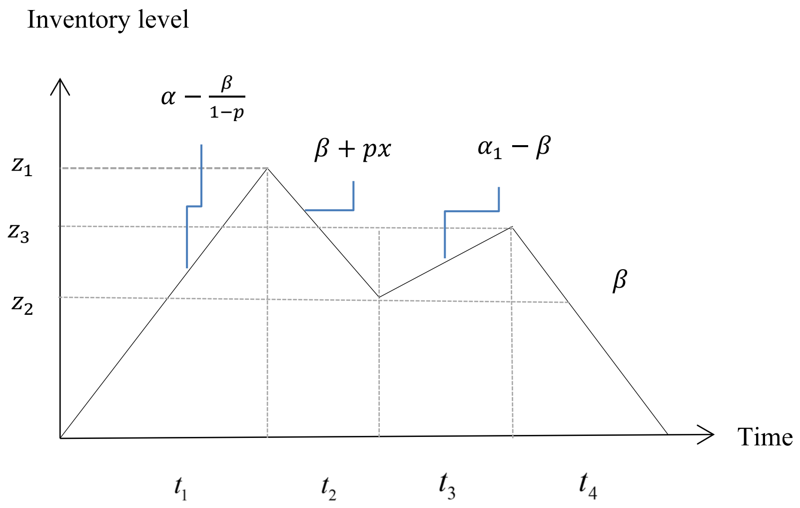
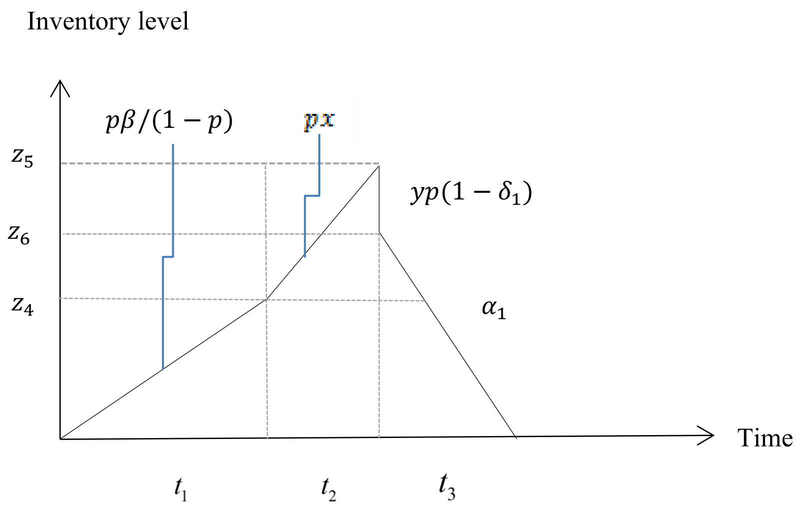


Figure 2. Inventory level of defective products



During period t_1, y units of products are manufactured at a production rate of α and the products are inspected at a speed of $\frac{\beta}{1-p}$ and defective and defective-free products are separated. As a result of the inspection, the demand is met with the good products obtained with a speed of β, while defective products are piled up with a $\frac{p\beta}{1-p}$ speed ($\frac{\beta}{1-p} = \beta + \frac{p\beta}{1-p}$) (Moussawi-Haidar et al., 2016). Thus, at the end of the period t_1, the number of stock of uninspected products is z_1 and the number of stock of defective products is z_4. For the stock of uninspected products to be created in period t_1, the condition $\alpha - \frac{\beta}{1-p} > 0$ or $\alpha > \frac{\beta}{1-p}$ must be met. Otherwise, demand cannot be fully met in the period t_1.

In line with these explanations, since y amount of product is manufactured with speed α in period t_1

$$t_1 = \frac{y}{\alpha} \tag{1}$$

Furthermore, Figure 1

$$t_1 = \frac{z_1}{\left(\alpha - \frac{\beta}{1-p}\right)} \tag{2}$$

Eq (3) is deduced from Eqs (1) and (2).

$$z_1 = \left(1 - \frac{\beta}{\alpha(1-p)}\right) y \tag{3}$$

On the other hand, from Figure 2, the following amount of defective product z_4 at the end of t_1 period

$$z_4 = \left(\frac{p\beta}{1-p}\right) t_1 = \frac{p\beta y}{(1-p)\alpha} \tag{4}$$

is obtained.

In period t_2, z_1 pcs products are inspected at speed x and defective products and defective-free products are separated from each other. Demand is met from good products at speed β, and defective products are piled up at speed px as a result of the inspection.

$$t_2 = z_1/x = \left(1 - \frac{\beta}{\alpha(1-p)}\right) y/x \tag{5}$$

The basic assumption here is that to fulfill the demand, the inspection speed(x), must be greater than the inspection speed $\left(\frac{\beta}{1-p} = \beta + \frac{p\beta}{1-p}\right)$ required to obtain β quantity of good product per unit time. In this case, the condition $\frac{\beta}{(1-p)} < x$ must be satisfied. The two conditions mentioned above can be written as $\alpha > \frac{\beta}{(1-p)} < x$. It is thus seen that there is no boundary condition in the association between the production rate α and the inspection rate x. In other words, it can be $\alpha < x$ or $\alpha > x$.

At the end of the period t_2, the inspection process ends and the total quantity of defective products is z_5

$$z_5 = py \tag{6}$$

Scrap and low-quality products are removed from the defective product stock and low-quality products are sold in bulk (in lots). In this case, the repairable product quantity is

$$z_6 = z_5 - (1-\delta_1)py = \delta_1 py \tag{7}$$

obtained. From Figure 1;

$$t_2 = \frac{z_1 - z_2}{\beta + px} \tag{8}$$

From Eqs (5) and (8); we get

$$z_2 = (1 - p - \beta/x)\left(1 - \frac{\beta}{\alpha(1-p)}\right)y \tag{9}$$

At the end of the period t_2, the quantity of good products is z_2 pcs.

During the period t_3; z_6 pcs defective products are repaired with α_1 speed; and are deducted from the defective product stock in Figure 2, and added to the good product stock in Figure 1.

From here we get

$$t_3 = z_6/\alpha_1 = \frac{\delta_1 py}{\alpha_1} \tag{10}$$

equation, on the other hand from Figure 1;

$$t_3 = \frac{z_3 - z_2}{\alpha_1 - \beta} \tag{11}$$

equation, from Eqs (9), (10) and (11); we get

$$z_3 = \left[(1 - p - \beta/x)\left(1 - \frac{\beta}{\alpha(1-p)}\right) + \delta_1 p(1 - \beta/\alpha_1)\right]y \tag{12}$$

At the end of the period t_3, the quantity of good products is z_3 pcs. z_3 pcs of good products fulfills the demand during t_4 with a rate β and hence from Figure 1; we obtain

$$t_4 = z_3/\beta = \left[(1 - p - \beta/x)\left(1 - \frac{\beta}{\alpha(1-p)}\right) + \delta_1 p(1 - \beta/\alpha_1)\right]y/\beta \tag{13}$$

Since the quantity of good products produced in a cycle is derived by deducting the quantity of scrap and low-quality products from the quantity of products manufactured and the cycle time (t) is obtained by the ratio of the quantity of good products to the demand rate; we have

$$t = \frac{[1 - (1 - \delta_1)p]y}{\beta} \tag{14}$$

Total cost(TC), in one cycle

$$TC = cy + dy + m\delta_2 py + c_r\delta_1 py + K + h\left[\frac{t_1 z_1}{2} + \frac{t_2(z_1 + z_2)}{2} + \frac{t_3(z_2 + z_3)}{2} + \frac{t_4 z_3}{2}\right]$$

$$+h_1\left[\frac{t_1 z_4}{2} + \frac{t_2(z_4 + z_5)}{2} + \frac{t_3 z_6}{2}\right]$$

$$= cy + dy + m\delta_2 py + c_r\delta_1 py + K + \left\langle \frac{(h_1 - h)}{2}\left\{\frac{\beta}{\alpha}\left[\frac{1}{\alpha}\left(\frac{p}{1-p}\right) - \frac{\beta}{\alpha x}\left(\frac{p}{(1-p)^2}\right)\right] + \frac{p}{x} + \frac{p^2\delta_1^2}{\alpha_1}\right\}\right.$$

$$\left. + \frac{h}{2}\left\{\frac{1}{\beta} - \frac{1}{\alpha} + 2p(1 - \delta_1)\left(\frac{1}{x} + \frac{1}{\alpha} - \frac{1}{\beta}\right) - \frac{2\beta(1 - \delta_1)}{\alpha\alpha_1}\left(\frac{p}{1-p}\right) + \frac{(1 - \delta_1)^2 p^2}{\beta}\right\}\right\rangle y^2 \tag{15}$$

total revenue (TR) in one cycle;

$$TR = s[1 - (1 - \delta_1)p]y + v\delta_3 py \tag{16}$$

and total profit (TP) in one cycle; we get

$$TP = TR - TC = \{s - c - d + [v\delta_3 - s(1 - \delta_1) - m\delta_2 - c_r\delta_1]p\}y - K$$

$$-\left\langle\frac{(h_1-h)}{2}\left\{\frac{\beta}{\alpha}\left[\frac{1}{\alpha}\left(\frac{p}{1-p}\right)-\frac{\beta}{\alpha x}\left(\frac{p}{(1-p)^2}\right)\right]+\frac{p}{x}+\frac{p^2\delta_1^2}{\alpha_1}\right\}\right.$$

$$\left.+\frac{h}{2}\left\{\frac{1}{\beta}-\frac{1}{\alpha}+2p(1-\delta_1)\left(\frac{1}{x}+\frac{1}{\alpha}-\frac{1}{\beta}\right)-\frac{2\beta(1-\delta_1)}{\alpha\alpha_1}\left(\frac{p}{1-p}\right)+\frac{(1-\delta_1)^2p^2}{\beta}\right\}\right\rangle y^2 \quad (17)$$

Since the percentage of defective products (x) is a random variable obeying a certain probability distribution, the expected total profit (ETP) in a cycle is

$$ETP = Fy - K - Ly^2 \quad (18)$$

Where $E[.]$ is the expected value operator and it can be written as follows

$$F = s - c - d + [v\delta_3 - s(1-\delta_1) - m\delta_2 - c_r\delta_1]E[p]$$

$$L = \left\langle\frac{(h_1-h)}{2}\left\{\frac{\beta}{\alpha}\left[\frac{1}{\alpha}E\left[\frac{p}{1-p}\right]-\frac{\beta}{\alpha x}E\left[\frac{p}{(1-p)^2}\right]\right]+\frac{E[p]}{x}+\frac{\delta_1^2E[p^2]}{\alpha_1}\right\}\right.$$

$$\left.+\frac{h}{2}\left\{\frac{1}{\beta}-\frac{1}{\alpha}+2(1-\delta_1)\left(\frac{1}{x}+\frac{1}{\alpha}-\frac{1}{\beta}\right)E[p]-\frac{2\beta(1-\delta_1)}{\alpha\alpha_1}E\left[\frac{p}{1-p}\right]+\frac{(1-\delta_1)^2E[p^2]}{\beta}\right\}\right\rangle$$

On the other hand, the expected value of the cycle time can be written as follows

$$E[t] = \frac{Jy}{\beta} \quad (19)$$

Here we have

$$J = 1 - (1-\delta_1)E[p]$$

The expected total profit function per unit time (ETPU) is obtained as follows

$$ETPU\ (y) = \frac{ETP}{E[t]} = \frac{F\beta}{J} - \frac{K\beta}{Jy} - \frac{L\beta y}{J} \quad (20)$$

If the derivative of the expected profit function concerning y is taken and equalized to zero, we have

$$\frac{\partial ETPU}{\partial y} = \frac{K\beta}{Jy^2} - \frac{L\beta}{J} = 0 \quad (21)$$

and from here we get

$$y = \sqrt{\frac{K}{L}} \quad (22)$$

the formula of the economic production quantity

$$\frac{\partial ETPU}{\partial y} = \frac{K\beta}{Jy^2} - \frac{L\beta}{J} = 0 \quad (23)$$

Taking the second derivative of the equation, it is clear that $ETPU\ (y)$ is strictly a concave function.

$$\frac{\partial^2 ETPU(y)}{\partial y^2} = -\frac{2K\beta}{Jy^3} < 0 \tag{24}$$

On the other hand, it would be a correct approach to obtain the solution values of the equations mentioned above from the expected value functions. The expected value functions of these equations can be written as follows:

$$E[z_1] = \left(1 - \frac{\beta}{\alpha} E\left[\frac{1}{1-p}\right]\right) y \tag{25}$$

$$E[z_4] = \left(\frac{\beta}{\alpha} E\left[\frac{p}{1-p}\right]\right) y \tag{26}$$

$$E[t_2] = \left(1 - \frac{\beta}{\alpha} E\left[\frac{1}{1-p}\right]\right) y/x \tag{27}$$

$$E[z_5] = (E[p])y \tag{28}$$

$$E[z_6] = (\delta_1 E[p])y \tag{29}$$

$$E[z_2] = \left\{(1 - \beta/x)\left(1 - \frac{\beta}{\alpha} E\left[\frac{1}{1-p}\right]\right) - E[p] + \frac{\beta}{\alpha} E\left[\frac{p}{1-p}\right]\right\} y \tag{30}$$

$$E[t_3] = \left(\frac{\delta_1 E[p]}{\alpha_1}\right) y \tag{31}$$

$$E[z_3] = \left[(1 - \beta/x)\left(1 - \frac{\beta}{\alpha} E\left[\frac{1}{1-p}\right]\right) - E[p] + \frac{\beta}{\alpha} E\left[\frac{p}{1-p}\right] + \delta_1 E[p](1 - \beta/\alpha_1)\right] y \tag{32}$$

$$E[t_4] = \left[(1 - \beta/x)\left(1 - \frac{\beta}{\alpha} E\left[\frac{1}{1-p}\right]\right) - E[p] + \frac{\beta}{\alpha} E\left[\frac{p}{1-p}\right] + \delta_1 E[p](1 - \beta/\alpha_1)\right] y/\beta \tag{33}$$

2.2. Numerical Application

A numerical example was provided in this section to demonstrate the applicability of the proposed EPQ model. The example application presented in the study by Eroğlu and Arslan (2022) was discussed and the repair rate was assumed to be different due to model assumptions.

A factory manufactures a single item. The daily demand for this product is 1200 pieces, and the factory's production capacity is 5000 pieces per day. In the imperfect production process, the products are inspected and separated into defective and defective-free products. The daily capacity for inspection is 4000 pieces. The cost of a unit inspection is 1.2 TL. The percentage of repaired products in defective products is 0.50, the percentage of scrap is 0.20, and the percentage of low-quality products is 0.30. The daily capacity for repair is 2000 pieces. The cost of unit repair is 10 TL and the cost of unit production is 50 TL. The preparation cost is 16700 TL, the selling price of the good product is 90 TL, the selling price of the low-quality product is 60 TL, and the unit scrap product disposal cost is 5 TL. The cost of unit inventory is 2 TL, and the cost of inventory of defective products is 3 TL.

Solution 1:

Assume that the percentage of defects obeys a continuous uniform distribution and the probability density function is

$$f(p) = \begin{cases} 25, & 0{,}03 \leq p \leq 0{,}07 \\ 0, & otherwise \end{cases}$$

In this case, the model parameters are:

$\beta = 1200,\ \alpha = 5000,\ \alpha_1 = 2000,\ x = 4000\ ,\ \delta_1 = 0{,}50,\ \ \delta_2 = 0{,}20,\ \delta_3 = 0{,}30$

$c_r = 10,\ c = 50,\ K = 16700,\ d = 1{,}2\ , m = 5\ , s = 90,\ v = 60\ , h_1 = 3,\ h = 2.$

Expected values are calculated as E(p) = 0,05, $\mathrm{E}\left[\frac{p}{1-p}\right] = 0{,}052787$, $\mathrm{E}[p^2] = 0{,}002633$, $\mathrm{E}\left[\frac{p}{(1-P)^2}\right] = 0{,}055737$ $\mathrm{E}\left[\frac{1}{1-p}\right] = 1{,}052787$ and the following solution is obtained.

$y = 5.208{,}20$ unit	$E[t] = 4{,}231661$ day	$ETPU = 37.830{,}19$ TL
$E[t_1] = 1{,}04164$ day	$E[z_1] = 3.892{,}25$ unit	$E[z_5] = 260{,}41$ unit
$E[t_2] = 0{,}97306$ day	$E[z_2] = 2.530{,}15$ unit	$E[z_6] = 130{,}20$ unit
$E[t_3] = 0{,}06510$ day	$E[z_3] = 2.582{,}23$ unit	
$E[t_4] = 2{,}15186$ day	$E[z_4] = 65{,}98$ unit	

Solution 2:

Assume that the percentage of defect follows a normal distribution with mean $\mu = 0.08$, and standard deviation $\sigma = 0.02$.

In this case, the model parameters are:

$\beta = 1200,\ \alpha = 5000,\ \alpha_1 = 2000,\ x = 4000\ ,\ \delta_1 = 0{,}50,\ \ \delta_2 = 0{,}20,\ \delta_3 = 0{,}30$

$c_r = 10,\ c = 50,\ K = 16700,\ d = 1{,}2\ , m = 5\ , s = 90,\ v = 60\ , h_1 = 3,\ h = 2.$

The expected values are calculated as E(p) = 0.08, $\mathrm{E}\left[\frac{p}{1-p}\right] = 0.08746$, $\mathrm{E}[p^2] = 0.00680$, $\mathrm{E}\left[\frac{p}{(1-P)^2}\right] = 0.09567$ $\mathrm{E}\left[\frac{1}{1-p}\right] = 1.08730$ and the following solution is obtained.

$y = 5.252{,}05$ unit	$E[t] = 4{,}201638$ day	$ETPU = 37.250{,}72$ TL
$E[t_1] = 1{,}05041$ day	$E[z_1] = 3.881{,}52$ unit	$E[z_5] = 420{,}16$ unit
$E[t_2] = 0{,}97038$ day	$E[z_2] = 2.407{,}14$ unit	$E[z_6] = 210{,}08$ unit
$E[t_3] = 0{,}10504$ day	$E[z_3] = 2.491{,}17$ unit	
$E[t_4] = 2{,}07598$ day	$E[z_4] = 110{,}24$ unit	

3. CONCLUSION

Because the basic assumptions of the classical EPQ model are insufficient for expressing real-world production environments, researchers have extended this model under different assumptions. Thus, new models that include situations and uncertainties such as stock-outs, demand fulfillment, quality control, rework, learning effects and inflation have better represented industrial problems. In this study, an EPQ model is developed for the case where scrap products in defective products are removed at a certain cost, low-quality products are sold at a discounted price and repairable products are reworked after production and inspection processes for each cycle are completed. The validity of the model is demonstrated by numerical example.

This work can be extended by assuming different demand functions and the production of multiple products in the production process.

REFERENCES

1. AYDEMİR, E. (2015). "Envanter Yönetimi ve Uzantıları: Ekonomik Üretim Miktarı Modelleri Üzerine Bir Bilimsel Yazın Araştırması", Anadolu Üniversitesi Sosyal Bilimler Dergisi, 15 (3), 97-112.

2. CHAN, W.M., IBRAHIM, R.N. & LOCHERT, P.B. (2003). "A New EPQ Model: Integrating Lower Pricing, Rework and Reject Situations, Production Planning and Control", 14(7), 588-595.

3. DEMİR, H. ve GÜMÜŞOĞLU, Ş., (2003). Üretim Yönetimi (İşlemler Yönetimi), Beta Yayıncılık.

4. EROĞLU, A., (2002). Deterministik Envanter Modelleri (1. Baskı), Fakülte Kitabevi.

5. EROĞLU, A. & ARSLAN, P. (2022). "New Expansions In The Economic Production Quantity Model Containing Defective Products", International Journal of Engineering and Innovative Research, 4(2), p:126-133.

6. EROĞLU, A., SÜTÇÜ, A. & SULAK, H. (2008). "Rassal Olarak Kusurlu Üretim Yapan Üretim Süreçleri için Ekonomik Üretim Miktarı Modeli", Gazi Üniv. Müh. Mim. Fak. Der., 23(4), 923-929.

7. EROĞLU, Ş. & ŞAHİN, Y. (2023). "Geri Dönüşüm Süreci için Yeni Bir Bulanık Envanter Modeli", Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve mühendislik Dergisi 25(7), 21-36.

8. HAYEK, P.A. & SALAMEH, M.K. (2001). "Production Lot Sizing with the Reworking of Imperfect Quality Items Produced, Production Planning and Control", 12(6), 584-590.

9. KARAGÜL, N. (2021). Ekonomik Üretim Miktarı Model Önerileri ve Sembolik Hesaplama ile Çözümleri, (Yayımlanmamış doktora tezi), Süleyman Demirel Üniversitesi, Sosyal Bilimler Enstitüsü, Isparta.

10. LIAO, G-L. (2016). "Optimal economic production quantity policy for a parallel system with repair, rework, free-repair warranty and maintenance", International Journal of Production Research, 54:20, 6265-6280.

11. MOUSSAWI-HAIDAR, L., SALAMEH, N. & NASR, W. (2016). "Production Lot Sizing with Quality Screening and Rework, Applied Mathematical Modelling", 40 (4), 3242-3256.

12. ÖZTÜRK, H. (2017). “A Note on Production Lot Sizing with Quality Screening and Rework”, Applied Mathematical Modelling, 43, 659-669.

13. ROSENBLATT, M.J. & LEE, H.L. (1986). “Economic Production Cycles with Imperfect Production Processes”, IEE Transactions, 18, 48-55.

14. SANA, S. S. (2010). “An Economic Production Lot Size Model in an Imperfect Production System”, European Journal of Operational Research, 201, 158-170.

15. SARKAR, B., CARDENAS-BARRON, L.E., SARKAR, M. & SINGGIH, M.L. (2014). “An Economic Production Quantity Model with Random Defective Rate, Rework Process and Backorders for a Single Stage Production System”, Journal of Manufacturing Systems, 33, 423–435

16. SCHRADY, D.A. (1967). A Deterministic Inventory Model for Repairable Items”, Naval Research Logistics, 14 (3), 391–398.