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Environmentally Responsible EPQ Model with Rework Process of Defective Items

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Abstract: A real economic growth only comes from increasing quality and quantity of the factors of production. Most production systems produce items which are of imperfect quality. In a production/inventory situation items which are received or produced are not of perfect quality. Thus the presence of defects which is inevitable in a produced/ordered lot is sorted out by the process of screening. Handling of the defective items varies by industry and product types. For example, defective items may be dealt by the way of rework processor by sold at discount prices. To make the fulfillment of the demands in right proportion and at the right time, inventory models (Economic order/production quantity) were formulated. We consider an EPQ model with rework process of defective items with the inclusion of environmental costs. The expected profit functions are developed using renewal reward theory, and closed form of expressions for the optimal production lot size are derived with numerical example in different cases.

Keywords: Economic production quantity, Defective items, Rework, Environmental costs.

1. Introduction:

The purpose for production control was, and still is, to effectively utilize limited resources in the production of goods, so as to satisfy customer demands and goods, so as to create profit inventories. Organizations should always maintaining inventories of goods in order to ensure smooth and efficient running of its operations. Mathematical analysis is usually used to develop operating rules in order to determine when and in what quantity the inventory should be replenished, based on the minimization of an appropriate cost function which balances the total costs. Most traditional approaches to the problem of determining the economic ordering quantities have always assumed implicitly that items produced are of perfect quality. Product quality, however, is not always perfect. A proportion of the produced items can be found to be defective. These defective items can be reworked in the same cycle, when production stops, the demand for the initial perfect items and the perfect items being reworked is continuous during the cycle. A larger lot size requires a longer production cycle, and hence is more likely to contain more defective items.

We consider a machine purchasing a single item, with the possibility of producing a random proportion of defective items. To identify the defective items , screening is conducted at the end of the production period. Once identified, the defective items are reworked at a constant rate before they are returned to the inventory. A common assumption in the inventory literature with defectives is that the rework of a defective item is followed immediately after it is identified ([7],[13] and [18]). This assumption of continuous screening during production complicates the analysis and is not practical for most production systems, especially when the fraction of defective items is low and the production rate is high, which makes continuous screening during production very expensive. To simplify the analysis, it was assumed into two groups, good products and to be reworked products. On the other hand [8], avoids this assumption by integrating the screening process into the production lot sizing model with rework. Also several research works in the literature have explained about the screening process, for example,[21].In [8], defective items identified are reworked at a constant rate with no shortages are allowed.

There are many environmental issues that may arise from the production process. The focus of this study is the environmental implications. These environmental contributions come with associated costs that can no longer be ignored in logistics system. Generally, industry includes various sectors like manufacturing, energy, materials & mining, and transportation. So we could say the costs combinations of transportation, emission from transport, energy usage and waste produced by defectives as environmental costs.

This paper elucidates about rework process; comprises the formulation of an EPQ model with the inclusion of transportation cost, cost of emission from transportation, cost of energy usage and wastage cost from defectives, presents a numerical example concludes the proposed work.

The remainder of the paper is organized as follows, Section 2 presents the literature review of the previous works cited. Section 3 presents notations and assumptions which are used in this model, Section 4 elucidates the model formation, In section 4.1 specials cases discussed, Section 5 gives numerical example and in section 6 concludes the proposed work.

2. Literature Review:

Inventory models with imperfect quality items have received significant attention in the literature. For a survey on these models, we refer the following,[17] Considers a production/inventory situation where items, received or produced, are not of perfect quality. In [13] the effect of imperfect quality items on the finite production model, when production stops, the defect items are assumed to be reworked at a constant rate were discussed. An economic production quantity model with random defective rate , rework process and backorders for a single stage production system was derived [2].In [20] examines the finite production model with a random defective rate and the imperfect rework process.[2] illustrates about production quantity model with random defective rate, rework process and backorders for a single stage production system.[5] investigates an EPQ model for imperfect quality items with non-sychronized screening and rework. Our work is closest to Lama Moussawi-Haidar[8] who analyze two models assumes that defective items are sold at a discount at the end of the production cycle and assumes that defective items are reworked at a constant rate.

In general, the need for transportation begins, when the retailers and the buyers are far apart from each other. Langley[9] discussed the need for the inclusion of transportation cost to the inventory model, Russell [16] derived the EOQ model with the inclusion of transportation cost of a single item. Carter[3] substantiated the importance of transportation cost in his work. Jaber[11] explicated the requirement of transportation along with the social cost that results from the emission of pollutants. Energy consumption is assumed to occur both during production and during the idle state of the machines [19] and Energy and resource efficiency is becoming an important strategy in manufacturing and it describes clearly in [22]. Also Bazan[1] considers energy used for manufacturing and remanufacturing.

In this paper we consider cost of transportation and cost of energy usage to the production process and cost of wastage, which produced by the defective items during rework process , since it is well known that rework is correcting of defective, so that portion waste can be produced from the rework process. Here we discussed a simplistic model that extends the EPQ model with reworking of defective items to include some environmental costs.

3. Notations and Assumptions:

The following notations and assumptions are used throughout to develop the EPQ model,

α	Production rate per unit time
α_1	Rework rate of defective items per unit time ,$\alpha_1 < \beta$
β	Demand rate of the final product per unit time
C_p	Unit production cost
d	Production rate of defective items per unit per unit time ,$d = \alpha P$
d_1	Screening cost per item during production
d_2	Screening cost per item after production stops
h	Holding cost per unit per unit time
h_1	Holding cost of defective items being reworked per unit per unit time ,$h_1 > h$
K	Fixed production setup cost
P	Random proportion of defective items, with probability density function f(P)

f(P)	Probability density function of P
s	Unit selling price of good quality items
t_1	Production time ,$t_1 = Y/\alpha$
t_2	Screening time
t_3	Time period to rework all defective items
T	Production cycle
x	Screening rate per unit per unit time
Y	Total number of items produced during a production cycle
C_r	Rework cost per unit
γ	Cost to dispose waste to the environment per unit
C	Cost of energy per unit
C_t	Cost of transportation
d_t	Distance travelled(from supplier to buyer, km)
a	Fixed cost per trip (mu)
b	Variable cost per unit transported per distance travelled (mu /unit/km)
t_c	Capacity of the vehicle
λ	Percentage of waste produced by the defective items per lot Y
β_1	Social cost from vehicle emission (mu / h)
v	Average velocity (Km / h)

The assumptions of this model are that,

- No shortages are allowed
- Demand during production is met from non-defective items only.
- Waste can be produced only by the defective items during rework process.
- Defective items are reworked at a constant rate.

4. Model formulation:

As in Salameh[8] model it is assumed that defective items are reworked at a constant rate α_1 ,with $\alpha_1 < \beta$. The time period needed to rework all defective items is t_3 , the rworked items are added to the inventory, and are used to satisfy demand during t_4,the remaining of the production cycle and $d = \alpha P$,where d is the production rate of defective items ,α production rate and P proportion of defective items. To avoid shortages , the number non-defective items produced should be greater or equal to the demand during production.

i.e. $N(y,t) \geq \beta t_1$, which implies $P \leq 1 - \frac{\beta}{\alpha}$.

Let TC(y) be the total cost per cycle. TC(y) is the summation of the production setup cost , unit production cost, screening cost during and after production, inventory holding cost, transportation cost, emission cost from transportation, cost of energy usage and cost of waste produced by the defective items .

As a result the total cost per cycle is written as ,

$$TC(y) = K + C_p y + C_r P y + d_1 \frac{\beta}{(1-P)} \frac{y}{\alpha} + d_2 y \left[1 - \frac{\beta}{\alpha} - \frac{P\beta}{\alpha(1-P)}\right]$$

$$+h\left[\frac{Z_1 t_1}{2} + \frac{(Z_1 + Z_2)t_2}{2} + \frac{(Z_2 + Z_3)t_3}{2} + \frac{Z_3 t_4}{2} + \frac{{t_1}^2 d}{2} + t_1 t_2 d\right] + h_1 \frac{\alpha_1 {t_3}^2}{2}$$

$$+\left(\frac{2a}{t_c} + b d_t y\right) + 2\beta_1 \frac{d_t}{v} + \left(\frac{Cy}{\alpha} + C\alpha_1 P y\right) + \gamma P \lambda y . \quad (1)$$

Let TR(y) be the total revenue per cycle. TR(y) is the selling price of good quality items. Thus it is written as ,

$$\mathrm{TR(y)} = \mathrm{sy}. \tag{2}$$

The total profit per cycle is the total revenue less the total cost , and is given as,

$$\mathrm{TP(y)} = \mathrm{sy} - \left[\mathrm{K} + \mathrm{C_p y} + \mathrm{C_r P y} + \mathrm{d_1}\frac{\beta}{(1-\mathrm{P})}\frac{\mathrm{y}}{\alpha} + \mathrm{d_2 y}\left\{1 - \frac{\beta}{\alpha} - \frac{\mathrm{P}\beta}{\alpha(1-\mathrm{P})}\right\}\right]$$

$$-\mathrm{h}\left[\frac{\mathrm{Z_1 t_1}}{2} + \frac{(\mathrm{Z_1}+\mathrm{Z_2})\mathrm{t_2}}{2} + \frac{(\mathrm{Z_2}+\mathrm{Z_3})\mathrm{t_3}}{2} + \frac{\mathrm{Z_3 t_4}}{2} + \frac{\mathrm{t_1}^2\mathrm{d}}{2} + \mathrm{t_1 t_2 d}\right] - \mathrm{h_1}\frac{\alpha_1 \mathrm{t_3}^2}{2}$$

$$-\left(\frac{2\mathrm{a}}{\mathrm{t_c}} + \mathrm{bd_t y}\right) - 2\beta_1\frac{\mathrm{d_t}}{\mathrm{v}} - \left(\frac{\mathrm{Cy}}{\alpha} + \mathrm{C}\alpha_1\mathrm{Py}\right) - \gamma\mathrm{P}\lambda\mathrm{y}\ . \tag{3}$$

Using the renewal – reward theorem [15] , the expected profit per unit time is the following

$$\mathrm{ETPU(y)} = \frac{\mathrm{ETP(y)}}{\mathrm{E(T)}}\ ,$$

Where ETP(y) is the expected profit per cycle, and E(T) the expected duration of the production cycle is $\mathrm{E(T)} = \frac{\mathrm{y}}{\beta}$. We get ,

$$\mathrm{ETPU(y)} = \mathrm{s}\beta - \mathrm{K}\frac{\beta}{\mathrm{y}} - \mathrm{C_p}\beta - \mathrm{C_r P}\beta - \mathrm{d_1}\frac{\beta^2}{\alpha}\mathrm{E}\left(\frac{1}{1-\mathrm{P}}\right) - \mathrm{d_2}\beta\left[1 - \frac{\beta}{\alpha} - \frac{\beta}{\alpha}\mathrm{E}\left(\frac{\mathrm{P}}{1-\mathrm{P}}\right)\right]$$

$$-\mathrm{hy}\left[\frac{\beta}{2\alpha}\left(1 - \frac{\beta}{\alpha} - \frac{\mathrm{d}}{\alpha}\right) + \frac{\beta}{\mathrm{x}}\left(1 - \frac{\beta}{\alpha} - \frac{\beta}{\alpha}\mathrm{E}\left(\frac{\mathrm{P}}{1-\mathrm{P}}\right)\right)\left\{\left(1 - \frac{\beta}{\alpha} - \frac{\mathrm{d}}{\alpha}\right) - \frac{\beta}{2\mathrm{x}}\left(1 - \frac{\beta}{\alpha} - \frac{\beta}{\alpha}\mathrm{E}\left(\frac{\mathrm{P}}{1-\mathrm{P}}\right)\right)\right\}\right.$$

$$+\left\{\left(1 - \frac{\beta}{\alpha} - \frac{\mathrm{d}}{\alpha}\right) - \frac{\beta}{\mathrm{x}}\left(1 - \frac{\beta}{\alpha} - \frac{\beta}{\alpha}\mathrm{E}\left(\frac{\mathrm{P}}{1-\mathrm{P}}\right)\right)\right\}\frac{\beta\mathrm{d}}{\alpha\alpha_1}$$

$$+\frac{1}{2}\left\{\left(1 - \frac{\beta}{\alpha} - \frac{\mathrm{d}}{\alpha}\right) - \frac{\beta}{\mathrm{x}}\left(1 - \frac{\beta}{\alpha} - \frac{\beta}{\alpha}\mathrm{E}\left(\frac{\mathrm{P}}{1-\mathrm{P}}\right)\right) - \frac{\beta\mathrm{d}}{\alpha\alpha_1}\right\}^2$$

$$\left.+\frac{\beta\mathrm{d}}{2\alpha^2} + \left(1 - \frac{\beta}{\alpha} - \frac{\beta}{\alpha}\mathrm{E}\left(\frac{\mathrm{P}}{1-\mathrm{P}}\right)\right)\frac{\beta\mathrm{d}}{\alpha\mathrm{x}}\right] - \mathrm{h_1 y}\frac{\beta\mathrm{d}^2}{2\alpha_1\alpha^2} - \frac{2\mathrm{a}\beta}{\mathrm{yt_c}} - \beta\mathrm{bd_t} - \frac{2\beta\beta_1\mathrm{d_t}}{\mathrm{yv}} - \frac{\beta\mathrm{C}}{\alpha}$$

$$-\beta\mathrm{C}\alpha_1\mathrm{E(P)} - \beta\gamma\lambda\mathrm{E(P)}. \tag{4}$$

To simplify the above expression, we define the following two expressions J and $\tilde{J}$ as

$$J \Rightarrow 1-\frac{\beta}{\alpha}-\frac{\beta}{\alpha}E\left(\frac{P}{1-P}\right) \quad \text{and} \quad \tilde{J} \Rightarrow 1-\frac{\beta}{\alpha}-\frac{d}{\alpha}=1-\frac{\beta}{\alpha}-E(P)$$

Then, the expected profit per unit time, $ETPU(y)$ in (4), becomes

$$ETPU(y) = s\beta - K\frac{\beta}{y} - C_p\beta - C_rP\beta - d_1\frac{\beta^2}{\alpha}E\left(\frac{1}{1-P}\right) - d_2\beta J$$

$$-hy\left[\frac{\beta}{2\alpha}\tilde{J}+\frac{\beta}{x}J\left(\tilde{J}-\beta\frac{J}{2x}\right)+\left(\tilde{J}-\frac{\beta}{x}J\right)\frac{\beta E(P)}{\alpha_1}+\frac{1}{2}\left(\tilde{J}-\frac{\beta}{x}J-\frac{\beta E(P)}{\alpha_1}\right)^2+\frac{\beta E(P)}{2\alpha}\right.$$

$$\left.+J\frac{\beta E(P)}{x}\right]-h_1y\frac{\beta E(P)^2}{2\alpha_1}-\frac{2a\beta}{yt_c}-\beta bd_t-\frac{2\beta\beta_1 d_t}{yv}-\frac{\beta C}{\alpha}-\beta C\alpha_1E(P)-\beta\gamma\lambda E(P)\,. \quad (5)$$

The optimal production quantity y^* is obtained by taking the derivative of the expected profit per unit time in (5) and by using the necessary condition

$$\frac{\partial(ETPU(y))}{\partial y}=0,$$

We get,

$$\frac{1}{y^2}\left(K\beta+\frac{2a\beta}{t_c}+\frac{2\beta\beta_1 d_t}{v}\right)=h\left[\frac{\beta}{2\alpha}\tilde{J}+\frac{\beta}{x}J\left(\tilde{J}-\beta\frac{J}{2x}\right)+\left(\tilde{J}-\frac{\beta}{x}J\right)\frac{\beta E(P)}{\alpha_1}\right.$$

$$\left.+\frac{1}{2}\left(\tilde{J}-\frac{\beta}{x}J-\frac{\beta E(P)}{\alpha_1}\right)^2+\frac{\beta E(P)}{2\alpha}+J\frac{\beta E(P)}{x}\right]+h_1\frac{\beta E(P)^2}{2\alpha_1}\,. \quad (6)$$

Hence ,the optimal production quantity y^* has the following expression,

$$y^* = \sqrt{\frac{2\,\beta\left(\frac{K}{2}+\frac{a}{t_c}+\frac{\beta_1 d_t}{v}\right)}{h\left[\frac{\beta}{2\alpha}\tilde{J}+\frac{\beta}{x}J\left(\tilde{J}-\beta\frac{J}{2x}\right)+\left(\tilde{J}-\frac{\beta}{x}J\right)\frac{\beta E(P)}{\alpha_1}+\frac{1}{2}\left(\tilde{J}-\frac{\beta}{x}J-\frac{\beta E(P)}{\alpha_1}\right)^2+\frac{\beta E(P)}{2\alpha}+J\frac{\beta E(P)}{x}\right]+h_1\frac{\beta E(P)^2}{2\alpha_1}}} \quad (7)$$

4.1. Special cases:

If all the items are of perfect quality , or the production rate is infinite, then we will check next that the optimal quantity obtained in (7) reduces to the economic production quantity.

Case(i)- All items are of perfect quality: In this case, we have P = 0, d = 0, $\alpha_1 \to \infty$, then $J \Rightarrow 1-\frac{\beta}{\alpha}$ and $\tilde{J} \Rightarrow 1-\frac{\beta}{\alpha}$,by replacing these values in (7) ,we get

$$y^* = \sqrt{\frac{2\,\beta\left(\frac{K}{2}+\frac{a}{t_c}+\frac{\beta_1 d_t}{v}\right)}{h\left[\frac{\beta}{2\alpha}\left(1-\frac{\beta}{\alpha}\right)+\frac{1}{2}\left(1-\frac{\beta}{\alpha}\right)^2\right.}}$$

$$= \sqrt{\frac{2\,\beta\left(K+\frac{2a}{t_c}+\frac{2\beta_1 d_t}{v}\right)}{h\left(1-\frac{\beta}{\alpha}\right)}} \qquad (8)$$

Which is the optimal quantity for the classical production problem.

Case(ii)-Infinite production rate and perfect quality items: In this case, we have P = 0 (no defective items), $\alpha \to \infty$, then $J \Rightarrow 1$ and $\tilde{J} \Rightarrow 1$,by replacing these values in (7) ,we get

$$y^* = \sqrt{\frac{2\,\beta\left(\frac{K}{2}+\frac{a}{t_c}+\frac{\beta_1 d_t}{v}\right)}{h\left(\frac{1}{2}\right)}}$$

$$= \sqrt{\frac{2\,\beta\left(K+\frac{2a}{t_c}+\frac{2\beta_1 d_t}{v}\right)}{h}} \qquad (9)$$

Case(iii)-Infinite production rate: In this case, for an infinite production rate ,$\alpha \to \infty$.

Then ,$J \Rightarrow 1$ and$\tilde{J} \Rightarrow 1-E(P)$,by replacing these values in (7) ,we get

$$y^* = \sqrt{\frac{2\,\beta\left(K+\frac{2a}{t_c}+\frac{2\beta_1 d_t}{v}\right)}{h\left((1-E(P))^2+\frac{2\beta E(P)}{x}+\frac{\beta^2 E(P)^2}{{\alpha_1}^2}\right)+h_1\frac{\beta E(P)^2}{\alpha_1}}} \qquad (10)$$

5. Numerical Example:

To illustrate the result obtained in this paper, a numerical example is built up. Consider an inventory system with the following characteristics.

β = 1200 units/yr , α = 1600 units/yr , C_p = \$104 , s = \$200/unit , x = 1unit/min, d_1= \$0.5 ,d_2 = \$0.6 , K = \$1500/cycle , h = \$20/unit/yr ,h_1 = \$22/unit/yr, α_1= 100 units/yr , C_r= \$8 ,a = 5, b = 0.5€ /unit/km ,d_t = 100 km,v = 60 ,t_c =100/trip,β_1= 0.5,C = 0.2 €/Kwh ,λ = 0.2, γ= \$2.
Assume that the inventory operation operates on an 8 hours/day, for 365 days a year, then the annual screening rate,x = 1*60*8*365=175 200 units/year.Also the proportion of defective items is uniformly distributed over the range [0 , 0.1], with the probability distribution function f(P) as follows,

$$f(P) = \begin{cases} 10, & \text{for } 0 \le P \le 0.1 \\ 0, & \text{otherwise.} \end{cases} \quad (11)$$

Using(11),we get the expected value expressions:E(P) = 0.05, $E\left(\frac{1}{1-P}\right) = 1.0536$, $E\left(\frac{P}{1-P}\right) = 0.0536$.
Then the optimal production quantity of y is derived from Eq. (7), we get $\mathbf{y^* = 539.57}$units. Substituting$y^* = 539.57$units in Eq.(5) the maximum profit per unit year is given as

ETPU(y) = \$46190.76/yr.

We check that the special cases , the optimal solution reduces to that of the classical economic production quantity model, also we have

Case(i)-All items are of perfect quality: Eq.(8) ,$\mathbf{y^* = 849.03}$units

Case(ii)-Infinite production rate and perfect quality items: Eq.(9) ,$\mathbf{y^* = 424.51}$units

Case(iii)-Infinite production rate: Eq.(10) ,$\mathbf{y^* = 372.75}$units

6. Conclusion:

This paper presents an Economic production quantity model with reworking process of defective items produced with the inclusion of some environmental costs (i.e. transportation, emission from transportation, energy usage and wastage from defectives). The equations to calculate the optimal total profit per unit time and order quantities are presented .Special cases of the model are discussed. A numerical example is provided to demonstrate its practical usage.

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