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Optimum Process Adjustment Under Inspection Errors with Considering the Cycle Time of Production and Two Markets for the Sale of Goods

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Abstract. This paper is devoted to the study of determining optimal process mean in system production with the two markets for the sale of goods. In this paper, we developed an absorbing Markov chain model in production systems where all items are inspected %100 for conformance with their specification limits. When the value of the quality characteristic of an item falls below a lower limit, the item is scrapped. If it falls above an upper limit, the item is reworked (reprocessed). Products items conformance with specification limits sold in a primary market or a secondary market. Flow of material through the production system can be modeled in an absorbing Markov chain. We included cycle time of production line in model. Also effects of inspection errors are investigated. Numerical examples are given to demonstrate the application of the proposed model.

Keywords: Quality Control; Production; Markov Chain; Process Targeting; Quality Inspection.

1. Introduction

In a manufacturing environment, a product has to go across a number of processes, undergoing diverse operations before obtaining a final form.

Due to the inherent and technological inconsistencies, it is bound to have some variations in the quality of the final product. In order to improve the overall characteristics of the product, quality control became an essential part of manufacturing [1]. One of the most importance decision problems in quality control is the determination and selection of the process parameters (mean and variance) to optimize a selected objective. It is important stems from the fact that selecting the optimal parameters has impact on quality, cost and customer satisfaction [2]. Each quality characteristics of produced item should be adjusted at special mean. When operator starts work of production in the production systems, he should adjust quality characteristics of production process on the certain value. During production of the items in the production process, experts consider certain specifications limits for inspection of the produced item. With comparing the value of quality characteristics in each item with these specification, it is to known, whether the product complies with the limits. If the items are in within the predetermined limits, sold in the first market and second market, otherwise they are being considered as waste.100% inspection is used as the mean of product quality control. Product satisfies the first specification limit is sold in a primary market at a regular price and products fails the first specification limit and satisfies the second one is sold in a secondary market at a reduced price. The product is reworked or scraped if it does not satisfy both specification limits. If the product needs to be reworking, it returned to production process and a corrective action is performed on it. Inspection process usually is done 100% to reduce the amount of waste. Operator adjusts process according to mean value of quality characteristics. When the process starts, if the process mean is set too low, the number of non-conforming items becomes high and high rejection costs is incurred. On the other hand, if the mean value is set too high, then the number of reworking actions becomes high, resulting in a higher reworking cost.

The process mean problem has attracted the attention of many researches for more than half a century. The optimal selection of production process parameters reduces the cost of production and improves profitability. Springer (1951) was the first to consider the problem of process targeting; the process mean that minimizes the total cost is obtained [3]. Then the initial targeting problem has been extended in many directions. Hunter and Kartha (1977) proposed a model to determine the optimum process target mean of a process that maximizes the expected total income [4]. Bisgaard et al (1984) modified that model of Hunter and Kartha where cans with quality characteristic below the lower specification limit are sold in secondary market at a reduced price proportional to the can content. [5] Boucher and Jafari (1991) extended the model of Hunter and Kartha by introducing a single sampling inspection plan instead of 100% inspection [6]. Lee and Elsayed (2002) considered the problem of optimum process mean and inspection limits with allocating alternative variable for inspecting quality characteristics in one of the two-stage process. Optimum process mean in their research is obtained through profit maximization that their objective function includes sale, production costs, inspection cost and scrapping costs [7]. Al-sultan and Pulak (2000) presented a mathematical model for obtaining optimal adjustment point in a two-stage production system and they just considered lower inspection limits [8]. Zinlong et al (2006) obtained mean and variance of process through cost function. They minimized the sum of costs included costs of deviation from target and costs of fixed adjustments [9]. Jinshyang et al (2000) considered lower control limit for product adaption evaluation and they emphasized that optimal mean is affected by production line and raw materials. They assumed that Production Cost of the item is the linear function of the raw materials used in the production of items [10].Wang et al (2004) presented method of optimal adjustment and optimal control based on integrated control [11]. Duffuaa and Gaally (2012) developed multi-objective optimization model which includes profit function and income and used Taguchi quadratic function [2]. Chen and Lai modified Al-Sultan and Pulak (2000) model to determine the optimum process target are within the specifications [12]. Shokri and Walid (2011) presented a loss model to maximize profit function to obtain process mean for continuous production systems [13]. Park et al (2011) obtained mean and inspection limits through maximization of profit function using frequent method of Gauss-seidl [14]. Chung and Hui (2009) and Wang et al (2004) and Lee, et al (2007) have investigated different aspects of optimal process adjustment problem.

In the current research, similar to Bowling et al. (2004) [17] the flow of a discrete production process is modeled based on absorbing Markov chain. In other words, in this process, all items do not reach the finished stage due to scrapping and reworking hence a stochastic process of a type called absorbing Markov chain will be adopted. The data required for such a model are (i) the probability of which an item goes from one stage of production to the next and (ii) the probability of reworking and scrapping items at various stages. At every stage of production, the item is inspected; if it does not conform to its specifications, it is either scrapped or reworked. The reworked item will be inspected again. We have added the cycle time of production in profit objective function. The cycle time is the time between productions of two successive items, which is computed based on the time of bottle-neck station. After inspecting each item, we use rework loops for reworking. Each item is inspected and if it is not within the specifications limits, item immediately is reworking or scrapping. Similar models have been presented by Fallahnezhad and Niaki (2010) and Fallahnezhad and Hosseininasab (2012).

2. Notations

The required notations are:

- U_2: The upper specification limit of quality characteristic for products of primary market
- U_1: The upper (lower) specification limit of quality characteristic for products secondary (primary) market
- L: Lower specification limit of quality characteristic for products secondary market
- P_{ij}: The probability of going from state i to state j
- f_{ij}: The long run probability of going from a non-absorbing state (i) to an absorbing state (j)
- a: Item price at the primary market
- r: Item price at the secondary market
- g: Give-away cost per unit of excess material
- R: Scrapping cost
- K_1: Coefficient of quality loss function for the quality

characteristics at the primary market

K_2 : Coefficient of quality loss function for the quality characteristics at the secondary market

TP : The total profit

P : The transition probability matrix

Q : The transition probability matrix of going from a non-absorbing state to another non-absorbing state

R : A matrix containing all probabilities of going from a non-absorbing state to another absorbing state (i.e., accepted or rejected item)

I: The identity matrix

O: A matrix with zero elements

M: The fundamental matrix

F: The absorption probability matrix

C : Cycle time of production

T : Time of production one item

H : Total production time in each period

$f(x)$: The normal distribution density function with unknown mean μ and variance σ^2

c : Production cost per item

i : Inspection cost per item

$\phi(.)$: Normal cumulative distribution function

$E(RP)$: The expected profit per item

$E(RVP)$: The expected profit per item at the primary market

$E(RVS)$: The expected profit per item at the secondary market

$E(PC)$: The expected processing cost

$E(SC)$: The expected scrapping cost

3. Model Development

Duffuaa.et al (2013) applied the sampling plan for inspecting produced items and they considered two markets for the selling produced items. We extended their model and considered one serial production system in which items are 100% inspected. We assume that there is an inspection station after each production station in production line and we use rework loops for inspecting the items. The quality performance measure of at item is represented by a random variable x with an adjustable mean μ and a constant variance σ^2. An item is sold in one of two markets with different profit/cost structures or scrapped or reworked. A produced item is called conforming if its quality characteristic is between U_1, U_2 $(U_1 < x < U_2)$ and it is sold in a primary market at a price $\$a$, and it is called non-conforming if its quality characteristic falls below L and it is scrapped. If x is between L, U_1 $(L < x < U_1)$ then it is sold in a secondary market at a reduced price $\$r$ $(a > r)$. If x falls above U_2 then it is reworked and it returned to the production process. Material flow in manufacturing system is modeled as an absorbing Markov chain. The item is then reworked, accepted and sold at the primary market, accepted and sold at the secondary market or scrapped. Raw materials come into the production system and finally the finished items are produced we see that a Markov chain represents different conditions of the raw materials, i.e., reworking, scrapping, accepting and selling at the primary markets or accepting and selling at the secondary markets. This stochastic process with discrete state space and discrete values of the stage variable becomes a discrete time Markov chain when the transition from one state to the next depends only on the current state. Among the states, some are transient and the others. Among the states, some are transient and the others absorbing. A Markov chain with one or more absorbing states is known as absorbing Markov chain (Pillai and Chandrasekharan 2008).

The expected profit per item in the production system with two markets under consideration can be expressed as follows:

$$E(RP) = [E(RVP) + E(RVS) - E(PC) - E(SC)] \tag{1}$$

Thus total profit can be obtained as follows,

$$TP = \frac{H}{C} E(RP) \tag{2}$$

where H / C is the total number of items produced in each production period. Consider a production system with two sale markets the following states:

State 1: An item is being processed in the production process

State 2: An item is accepted to be finished work and it is sold at the primary market

State 3: An item is accepted to be finished work and it is sold at the secondary market

State 4: An item is scrapped

The quality characteristic of an item in the production process follows normal distribution with unknown mean μ and standard deviation σ. Transition probability matrix can be expressed as follows:

$$P = \begin{array}{c c} & \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \end{array} & \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array} \tag{3}$$

Where P_{11} is the probability reworking or reprocessing an item, P_{12} is the probability of accepting and selling an item in primary market, P_{13} is the probability of accepting and selling an item in secondary market. P_{14} is the probability of scrapping an item in production process.

Since the quality characteristic of an item in production process a normal distribution with means μ and standard deviations σ, transition probabilities can be expressed as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{4}$$

$$P_{11} = \int_{U_2}^{+\infty} f(x)dx = 1 - \phi(U_1) \tag{5}$$

$$P_{12} = \int_{U_1}^{U_2} f(x)dx = \phi(U_2) - \phi(U_1) \tag{6}$$

$$P_{13} = \int_{L}^{U_1} f(x)dx = \phi(U_1) - \phi(L) \tag{7}$$

$$O = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \tag{8}$$

Transition probability matrix $P = \begin{pmatrix} Q & R \\ O & I \end{pmatrix}$ can be expressed as follows,

$$Q = \begin{pmatrix} P_{11} \end{pmatrix},\ O = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix},\ R = \begin{pmatrix} P_{12} \\ P_{13} \\ P_{14} \end{pmatrix},\ I = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$M = (I - Q)^{-1} \tag{9}$$

$$M = \frac{1}{1 - P_{11}} = m_{11} \tag{10}$$

$$F = M \times R = \begin{pmatrix} P_{12} / (1 - P_{11}) \\ P_{13} / (1 - P_{11}) \\ P_{14} / (1 - P_{11}) \end{pmatrix} = \begin{pmatrix} f_{12} \\ f_{13} \\ f_{14} \end{pmatrix} \tag{11}$$

Denoting the cycle time with the parameter C , following is obtained.

$C = T \times m_{11}$ (12)

The value m_{ii} represents the expected number of times that the transient state i is occupied before absorption occurs and t_i is the production time in transient state i also $P_{12} / (1 - P_{11})$ is the probability of probability of going from a state 1 to state 2 for each item. Considering this fact that the cycle time of a production line is equal to the processing time of one item, therefore Eq. (12) is obtained.

According to Eq (1), following is obtained,

$$TP = \frac{H}{C}\left[\left(a - g(X' - U_1) - K_1 \frac{\int_{U_1}^{U_2} \frac{1}{X^2} f(x)dx}{\int_{U_1}^{U_2} f(x)dx}\right) \times f_{12} + \left(r - g'(X'' - L) - K_2 \frac{\int_{L}^{U_1} \frac{1}{X^2} f(x)dx}{\int_{L}^{U_1} f(x)dx}\right) \times f_{13} - m_{11}(c\mu + i) - (R \times f_{14})\right] \tag{13}$$

where H / C is the number of produced items and,

$$E(RVP) = \left(a - g(X' - U_1) - K_1 \frac{\int_{U_1}^{U_2} \frac{1}{X^2} f(x)dx}{\int_{U_1}^{U_2} f(x)dx} \right) \times f_{12} \tag{14}$$

Where

X' is defined as the conditional expectation of the quality characteristic X given that is between U_1, U_2

$$X' = \frac{\int_{U_1}^{U_2} xf(x)dx}{\int_{U_1}^{U_2} f(x)dx} \tag{15}$$

And;

$$E(RVS) = \left(r - g'(X'' - L) - K_2 \frac{\int_{L}^{U_1} \frac{1}{X^2} f(x)dx}{\int_{L}^{U_1} f(x)dx} \right) \times f_{13} \tag{16}$$

Where

Also, X'' is defined as the conditional expectation of the quality characteristic X given that is between L, U_1:

$$X'' = \frac{\int_{L}^{U_1} xf(x)dx}{\int_{L}^{U_1} f(x)dx} \tag{17}$$

$$E(SC) = R \times f_{14} \tag{18}$$

$$E(PC) = m_{11}(c\mu + i) \tag{19}$$

Equation (20),(21) are the expected loss per inspected item of an accepted and sold in a primary market and secondary market, respectively.

$$g(X' - U_1) + K_1 \frac{\int_{U_1}^{U_2} \frac{1}{X^2} f(x)dx}{\int_{U_1}^{U_2} f(x)dx} \tag{20}$$

$$g'(X''-L)+K_2\frac{\int_L^{U_1}\frac{1}{X^2}f(x)dx}{\int_L^{U_1}f(x)dx} \tag{21}$$

Where

$$L\left(X\right)=k\frac{1}{X^2} \tag{22}$$

$L\left(X\right)$ is defined as the loss function of the larger the better tolerance type, in the Eq.(22), the ideal value of the quality characteristic is infinity, therefore the loss is zero, but in reality the value of the quality characteristic will never reach infinity, due to the fact that as the value of the quality characteristic increases, more production and give-away costs are incurred. Hence, the target value will be in a point of compromise between these costs and cost of nonconformity.

4. Numerical Examples

Consider a production system with two markets for selling of the goods and the following parameters: these parameters are partially taken from (S.O.Duffuaa, A. EI-Gaaly 2013).

$$\begin{array}{ll} a=80, & R=4, \\ c=6, & i=1, \\ g=g'=2, & \sigma=1, \\ K_1=K_2=1, & L=8, \\ U_1=11, & U_2=13, \\ r=67.5 & \end{array}$$

The expected profit is maximized at $\mu^*=10.025$ with expected profit of production will be $TP^*=45.9972$. The function TP is plotted versus decision variable μ in Figure (1).

Figure (1) shows that the expected profit is a function of the process mean.

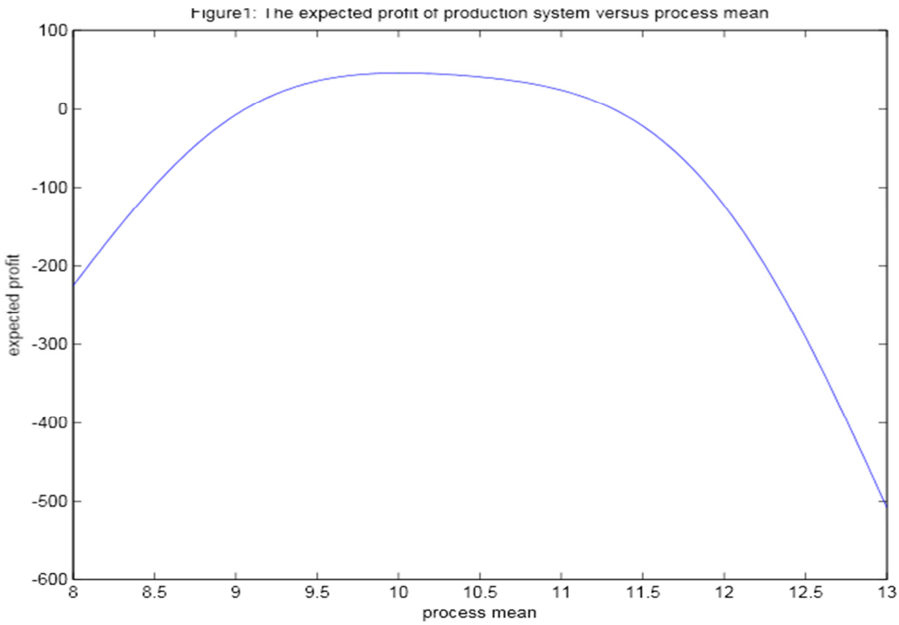

Figure 1.

5. Sensitivity Analysis

A sensitivity analysis of the proposed model is performed to illustrate the effects of estimated parameters on the optimal process mean and optimal expected profit. All parameters were varied in this production system and their effects have been denoted in this section.

Table 1 shows the behaviors of the optimal process mean and the optimal expected profit with the variation of the parameters for this production system.

Table 1: Behaviors of optimal mean and expected profit with the variation of the scrap and rework and processing costs

Sensitivity analysis for a production system with two sale markets				
Cost parameter	Case #	Value parameter	μ^*	TP^*
a	1	80	10.025	45.99
	2	100	11.20	146.56
	3	130	11.525	368.52
	4	150	11.625	527.41
	5	200	11.75	937.69
g_1	6	1	10.075	47.06
	7	2	10.025	45.99
	8	4	9.975	44.06
	9	7	9.90	41.50
	10	10	9.85	39.20
g_2	11	1	10.05	64.13
	12	2	10.025	45.99
	13	4	9.975	9.80
	14	7	9.75	-43.60
	15	10	11.175	-84.70
r	16	67.5	10.025	45.99
	17	80	9.80	177.32
	18	125	9.650	661.26
	19	150	9.625	931.37
	20	168	9.60	1.0936e+003
R	21	2	10	46.56
	22	4	10.025	45.99
	23	8	10.075	44.95
	24	12	10.125	44.018
	25	16	10.175	43.16
c	26	4	10.65	303.91
	27	6	10.025	45.99
	28	8	9.70	-199.72
	29	10	9.50	-439.04
	30	15	9.125	-1.190e+003

Sensitivity analysis for a production system with two sale markets				
Cost parameter	Case #	Value parameter	μ^*	TP^*
T	31	50	10.025	73.59
	32	80	10.025	45.99
	33	100	10.025	36.79
	34	120	10.025	30.66
	35	150	10.025	24.53
σ	36	0.25	8.60	163.97
	37	0.5	0.025	110.66
	38	1	10.025	45.99
	39	1.25	10.20	24.23
	40	1.5	10.15	-13.80
i	41	1	10.025	45.99
	42	3	10.025	20.99
	43	5	10.025	-4.002
	44	7	10.025	-29.002
	45	10	1.025	-66.50
K_1	46	1	10.025	45.99
	47	5	10.025	45.93
	48	10	10.025	45.86
K_2	49	1	10.025	45.99
	50	5	10.05	45.56
	51	10	10.05	45.02

It is observed Table 1 that the optimal expected profit and optimal process mean significantly increase as selling price of the items in primary decreases. Also it is seen from Table 1 that, by increasing the value of g_1, slightly values of μ^* and TP^* decrease. By increasing the value of g_2, significantly optimal expected profit decreases and slightly values of μ^* decreases. When value of r increases then value of μ^* decreases and the value of TP^* increases. It is seen from Table 1 that, by increasing the value of R, the value of μ^* increases and the value of TP^* decreases. By increasing the value of c the optimal expected profit and optimal process mean significantly decrease. When value of T increases, optimal process mean remains constant but the optimal expected profit decreases. By changing value of σ, the optimal process mean and the optimal expected profit change so that by increasing value of σ, significantly the value of TP^* decreases but then value of μ^* increases. Chang in the value of i has no effect on the value of μ^* but by increasing the value of i, the value of TP^* decreases. When the values of K_1 and K_2 increase then the value of TP^* slightly decreases but optimal process mean remains constant.

6. Inspection Error

100% inspection is used as the mean of product quality control and the inspection is not free of errors. There are two types of inspection errors in the inspection, type I and II. Type I error is classifying a conforming item as non-conforming. Type II error is classifying a non-conforming item as conforming. Therefore, the inspector rejects some conforming items and accepts other non-conforming ones due to the presence of the two types of error. Assume that α is the probability of Type I error, and β is the probability of Type II error. The probability of non-conforming is affected by the two types of error. If P'_{ij} denotes the probability of going from state i to state j in this case, we have

$$\begin{aligned} P'_{12} &= (1-\alpha)P(U_1 \le X \le U_2) + \beta\left(1 - P(U_1 \le X \le U_2)\right) \\ &= (1-\alpha)P_{12} + \beta(1-P_{12}) \end{aligned} \tag{23}$$

$$\begin{aligned} P'_{13} &= (1-\alpha)P(L \le X \le U_1) + \beta\left(1 - P(L \le X \le U_1)\right) \\ &= (1-\alpha)P_{13} + \beta(1-P_{13}) \end{aligned} \tag{24}$$

$$\begin{aligned} P'_{14} &= (1-\beta)P(X < L) + \alpha\left(1 - P(X < L)\right) \\ &= (1-\beta)P_{14} + \alpha(1-P_{14}) \end{aligned} \tag{25}$$

Also following is obtained:

$$\begin{aligned} P'_{11} &= 1 - P'_{12} - P'_{13} - P'_{14} \\ &= 1 - (1-\alpha)(P_{12} + P_{13}) - \beta\left(2 - (P_{12} + P_{13})\right) - P_{14}(1-\beta) - (1-P_{14})\alpha \end{aligned} \tag{26}$$

With the same discussion, now we can derive the Markov chain of production process in this case as follows,

$$Q = \left(P'_{11}\right), R = \begin{pmatrix} P'_{12} \\ P'_{13} \\ P'_{14} \end{pmatrix}, O = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, I = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{27}$$

Now we can evaluate the objective function in Eq. (13) and determine the optimal process adjustment under the presence of inspection errors. Table 2 denotes a Sensitivity analysis on the values of inspection errors.

Table 2: Behaviors of optimal mean and expected profit with the variation of inspection errors

inspection errors	Case #	Value parameter	μ^*	TP^*
	1	**(0,0)**	**10.025**	**45.99**
	2	**(0.05,0.05)**	9.85	55.04
	3	**(0.1,0.05)**	9.75	1.21
(α, β)	**4**	**(0.75,0.05)**	8.025	-544.68
	5	**(0.1,0.2)**	9.47	199.03
	6	**(0.1,0.3)**	9.25	335.32
	7	**(0.3,0.1)**	9.25	-138.42

It is observed in Table 2 that by increasing the values of α, β, the optimum value of μ^* decreases but the optimum value of TP^* increases. By increasing the value of β, the optimum value of μ^* decreases but the optimum value of TP^* increases that means that in the case of existing inspection errors, the optimal adjustment of process is more important. Also it is seen from Table 2 that by increasing α the optimum value of μ^* and TP^* decreases denoting that probability of Type I error decreases the total profit of the system but β can increase the total profit of the system. This result can be justified because we have not considered the cost of waste products that will come back from customers.

7. Conclusion

In this paper, absorbing Markov chain model with the two markets for the sale of goods were developed to determine the optimal process means that maximize the expected profit per item of production systems in which the items are %100 inspected to be classified as accepting and selling in a primary market, accepting and selling in secondary market, scrapping, reworking (reprocessing) ones. Also performance of proposed methodology under inspection errors is investigated. Numerical example was provided to illustrate the applications of the proposed model.

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