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A Real Application on Economic Design of Control Charts with R-edcc Package

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--**ABSTRACT**--

Control charts are the most popular process monitoring tools to detect changes in the product quality. Some design parameters should be determined to create a control chart. These parameters are sample size, sampling interval, and control limits. Selecting of these parameters economically is prominent topic and called the economic design of control charts. The purpose of the economic design is to combine parameters for minimizing production costs. Economic design of process control charts has been investigated by many researchers for sixty decades. Different models are developed for economic design of control charts by many researchers to minimize the cost function. In recent years, researchers focus on software for economically detecting the design parameters. Majority of the applications made up in recent years are carried out using MATLAB, C, SAS etc. Zu and Park first developed a software package in R which is named as edcc for the economical design of control charts in 2013. This paper presents a economic design of the control charts in a real production process using R edcc package. In this study, a pharmaceutical production process is handled. This study aims to show how the control charts design economically on a real life problem.

Keywords- *Control charts, Economic design, Pharmaceutical sector, Real application, R-edcc*

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I. INTRODUCTION

In recent years, owing to the globalization of production process and markets, quality has become more important factor. Firms have realized that production processes must be monitored regularly for producing quality products. In order to obtain and maintain quality, production processes are followed using appropriate tools. Control charts are widely used for controlling process in service and industrial sectors. The Control Chart is a graph used to study how a process changes over time with data plotted in time order. The uses of control charts allow reducing the scrap rate and costs by determining shifts occur during production on time. At this stage, design of the control charts becomes importance. Economic design of a chart is to combine parameters which are sample size, sampling interval and control limits so as to minimize production costs. First study on economic design of control charts is carried out by Duncan [1]. Duncan developed a economic model for X-bar charts when the production is subject to assignable cause that cause a out of control condition. Gedl et al. [2] advised an algorithm to seek for the optimal solution of control chart's parameters Duncan [3] investigated the situation which is two assignable causes in the production process. After Duncan's study, numerous papers have been proposed about economic design of control charts. Montgomery [4] developed the optimization procedures for determining optimal parameters for the x-bar control chart. Lorenzen and Vance [5] developed a unified function for economic design of all types of control charts. A literature review about the economic design of control charts for 1981-1991 was done by Ho and Case [6]. The economic design of CUSUM (cumulative sum) control charts was first introduced by Taylor [7]. Goel and Wu [8] and Chiu [9] proposed algorithms for determining the design parameters the CUSUM charts. Simpson and Keats [10] determined significant parameters of CUSUM control charts in using two-level fractional factorial designs. Lashkari and Rahim [11] proposed a model for economic design of CUSUM chart to follow non-normal process means. Torng, Montgomery, and Cochran [12] and Ho and Case [6] designed exponentially weighted moving average (EWMA) chart using Lorenzen-Vance [5] cost function. Montgomery et al. [13] presented a paper on the statistically constrained economic design of EWMA control charts, by using the Torng's model.

In recent years, researchers focus on software for economically detecting the the design parameters. Majority of the applications made up in recent years are carried out using MATLAB, C, SAS etc. Cheng and Guo [14] proposed a genetic algorithm for economic design of x-bar charts by using Matlab. Anasuri [15]) developed an ant colony algorithm for economic design of x-bar charts on C program. Zu and Park[16] first developed a software package in R which is named as **edcc** for the economical design of control charts in 2013. In this article, Tablet production process was analyzed for industrial application of economic design of control charts.

II. ECONOMIC DESIGN OF THE CONTROL CHARTS

In a simple way, economic design of a control chart is to search the answers of following questions for the minimum costs;

1. What should the sampling period be?
2. What should the sampling size be?
3. What should the charts limit be?

The answers of these questions are combined by taking into account a set of cost criteria. These are sampling cost, cost of process out of control state, cost of process in-control state, cost of false alarms, cost of investigating assignable cause and maintenance cost. Objective of economic design is to develop production performance and to reduce production and inspection costs.

There are a lot of parameters take into consideration for the design of control charts. These parameters are presented as following:

n= Sample size
h= Sampling interval
L= Width of the control limits
μ_0= Process mean when the process is in-control
μ_1= Process mean when the process is out of control
σ= Standard deviation of the quality characteristic
δ= Magnitude of the shift in the mean, when the process is out of control condition $\mu_1 = \mu_0 + \delta\sigma_0$
s= Expected number of samples taken when the process is in-control state
λ= Exponential distribution parameter for run length in control
τ= Expected time of occurrence of the assignable cause between two samples
ARL_1: Average run length when the process is in control condition.
ARL_2: Average run length when the process is out of control condition
T_0: Sampling time for one item
T_c: Expected time for investigating the assignable cause
T_f : Expected time for searching false alarm
T_r: Expected time for repairing process
d_1: Indicator for condition of production (If production continues during searches 1, otherwise 0)
d_2: Indicator for condition of production (If production continues during repair 1, otherwise 0)
a: Fixed sampling cost
b: Variable sampling cost
C_r: Searching and repairing cost for an assignable cause, containing any downtime.
C_f : Cost per false alarm
C_0: Cost of nonconforming item produced per hour when the process is in-control
C_1: Cost of nonconforming item produced per hour when the process is out of control ($C_1 > C_0$).

Economic design of control charts models usually expresses via total cost function. This function denotes the relation between design parameters and costs mentioned above. These costs are analyzed to obtain expected cost per time unit [17].
In this paper, accomplishment of economic design of a control chart is defined by expected cost per hour (ECH). ECH is obtained by equation (1):

$$\mathrm{ECH} = \frac{\mathrm{ECC}}{\mathrm{ECT}} \qquad (1)$$

ECC shows expected cycle cost and ECT shows expected cycle time [16] .Each cycle composed of production, monitoring and maintenance or adjustment. Every cycle starts with the production in-control condition and goes on until the out-of-control condition occurs on the chart and after adjustment or maintenance is completed. Thus, process return the in-control condition and new cycle starts [18]. ECC and ECT are formulated as follows [16]:

$$\mathrm{ECC} = \frac{C_0}{\lambda} + C_1(-\tau + \mathrm{n}T_0 + (ARL_2) + d_1T_c + d_2T_r) + \frac{sC_f}{ARL_1} + \frac{\frac{1}{\lambda} - \tau + \mathrm{n}T_0 + h(ARL_2) + d_1T_c + d_2T_r}{h} \qquad (2)$$

$$\mathrm{ECT} = \frac{1}{\lambda} + (1 - d_1)\frac{s}{ARL_1}T_f - \tau + nT_0 + h(ARL_2) + T_c + T_r \quad (3)$$

X-bar chart, EWMA chart and CUSUM chart are compared according to the ECH values. In the optimization problem, optimum chart parameters are searched for the minimum ECH value.

2.1.X-bar Chart

The lower control limit and upper control limit for the X-bar chart are obtained by equation (4) and (5):

$LCL_{X\text{-bar}}$: $\mu_0 - L\sigma_0 / n^{0.5}$ (4)

$UCL_{X\text{-bar}}$: $\mu_0 + L\sigma_0 / n^{0.5}$ (5)

At any sampling time, sample average is calculated and controlled whether it is inside control limits or not. If it is out of limits, X-bar chart gives an out of control signal. This signal shows that an assignable cause occurs. A search for detecting the assignable cause is starts. Optimum values of n, h and L parameters minimized the ECH are investigated for economic design of the X-bar control chart.

2.2.EWMA Chart

The exponentially weighted moving average (EWMA) is defined as in equation (6):

$z_i = wx_i + (1 - w)z_{i-1}$ (6)

w is a smoothing constant for the EWMA chart, $0 < w \leq 1$ and $z_0 = \mu_0$

The lower control limit and upper control limit for the EWMA chart are offered in equation (7) and (8):

$UCL_{EWMA} = \mu_o + L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{w}{2-w}}$ (7)

$LCL_{EWMA} = \mu_o - L\frac{\sigma}{\sqrt{n}}\sqrt{\frac{w}{2-w}}$ (8)

When value of z_i is outside the EWMA control limits, the process is out of control condition and an investigation starts for the assignable cause. Optimum values of n, h, w and L parameters minimized the ECH are investigated for economic design of the X-bar control chart.

2.3. CUSUM chart

The CUSUM chart includes all information about sample values by charting the cumulative sums of the deviations of the successive sample means from a target specification. The following statistics are used to monitor the process mean using a CUSUM chart. All equations about CUSUM chart are offered by equations (9), (10), and (11):

C^+ and C^{--} are upper and lower CUSUM respectively

x_i i th observation

k (reference value) is generally set to $\frac{|\mu_1 - \mu_0|}{2}$

$C_i^+ = max\{0, C_{i-1}^+ + z_i - k\}$ (9)

$C_i^- = max\{0, C_{i-1}^- - z_i - k\}$ (10)

$$z = \frac{\overline{x}-\mu_0}{\sigma/\sqrt{n}} \quad (11)$$

When the C^+ or C^- exceeds a decision interval H, the process is out of control condition. Decision interval H is generally taken 4 σ or 5 σ[19].

III. FUNCTIONS OF R-edcc

The R package edcc functions are listed as follows: **Function ecoXbar:** The function ecoXbar computes the optimum values of n (sample size), h (sampling interval) and L (coefficient of control limits) to design economically X-bar charts. This function is used as:

```
ecoXbar(h, L, n, lambda = 0.05, delta = 2, P0 = NULL, P1 = NULL,
C0 = NULL, C1 = NULL, Cr = 25, Cf = 50, T0 = 0.0167, Tc = 1,
Tf = 0, Tr = 0, a = 1, b = 0.1, d1 = 1, d2 = 1, nlevels = 30,
sided = "two", par = NULL, contour.plot = FALSE, call.print = TRUE,
...)
```

n levels: Number of counter levels required. This argument works only when contour.plot = TRUE.
sided: ‘one’ or ‘two’ is chosen for X-bar chart.

par: first value of the parameters to be optimized over

contour.plot: It gives information about whether a contour plot is drawn. TRUE or FALSE is chosen.

call.print: It gives information about whether the call is printed on the contour plot.

the other arguments are explained in the previous section.

If n, h, L are undetermined, ecoXbar function attempts to find global optimum point for minimizing ECH value. If h and L are undetermined but n is defined, ecoXbar function Function contour to find the optimum point for every n value. If h, L and n parameters are defined, ecoXbar function utilizes the grid method to obtain the optimum point. You can see Zu and Park [16] for more details.

Function ecoEwma: The function ecoEwma calculates the optimum parameters, n (sample size), h (sampling interval), w (weight to the present sample) and k (number of standard deviations from control limits to the center line) for the economic design of the EWMA control chart. It is used as:

```
ecoEwma(h = seq(0.7, 1, by = 0.1), w = seq(0.7, 1, by = 0.1),
k = seq(2, 4, by = 0.1), n = 4:8, delta = 2, lambda = 0.05,
P0 = NULL, P1 = NULL, C0 = NULL, C1 = NULL, Cr = 25, Cf = 10,
T0 = 0.0167, Tc = 1, Tf = 0, Tr = 0, a = 1, b = 0.1, d1 = 1,
d2 = 1, nlevels = 30, sided = "two", par = NULL, contour.plot = FALSE,
call.print = TRUE, ...)
```

w : It is between 0 and 1. It must be identified

If n, h, L are undetermined, ecoEwma function attemps to find global optimum point for minimizing ECH value. If h and L are undetermined but n is defined, ecoEwma function attemps to find the optimum point for every n value. If h, L and n parameters are defined, ecoEwma function utilizes the grid method to obtain the optimum point. You can see Zu and Park 2013 for more details.

Function ecoCusum: The function ecoCusum calculates the optimum parameters, n (sample size), h (sampling interval) and H (decision interval) for the economic design of the Cusum control chart. It is used as:

```
ecoCusum(h, H, n, delta = 2, lambda = 0.01, P0 = NULL, P1 = NULL,
C0 = NULL, C1 = NULL, Cr = 20, Cf = 10, T0 = 0, Tc = 0.1,
Tf = 0.1, Tr = 0.2, a = 0.5, b = 0.1, d1 = 1, d2 = 1, nlevels = 30,
sided = "one", par = NULL, contour.plot = FALSE, call.print = TRUE,...)
```

H: Decision interval. H is a numeric vector or left indefinite

If n, h, L are undetermined, ecoCusum function attempts to find global optimum point for minimizing ECH value. If h and H are undetermined but n is defined, ecoCusum function attempts to find the optimum point for every n value. If h, H and n parameters are defined; ecoCusum function utilizes the grid method to obtain the optimum point. You can see Zu and Park 2013 for more details.

Function contour: The function contour is used to compose contour plot for an ecdd class object (EcoXbar, EcoEwma or EcoCusum). The function is only works when the parameters h, L and n are all identified. It is used as follows:

contour (x, call.print = TRUE, ...)

x is edcc class object

call.print: It checks whether the call should be printed on the contour plot

...: Other arguments to be passed to contour function.

Function update: The function updates the model. It is carried out by extracting the call stocked in the object. It is used as follows:

update(object, ..., evaluate = TRUE)

object: An object of "edcc" class

…: Arguments which is changed are written

Evaluate: When the evaluate is true, new call else return the call.

IV. A CASE STUDY IN A PHARMACEUTICAL INDUSTRY

A pharmaceutical company was selected for application of this study. The company is one of the leading and oldest companies in Turkish pharmaceutical markets. The factory in Istanbul produces a wide range of products both for the domestic and foreign markets. All pharmaceutical forms are produced here in line with the Good Manufacturing Practice and Good Laboratory Practices, oral solids and oral liquids, topical sterile ampoules. A tablet production process in this pharmaceutical factory was analyzed for this study. The tablet manufacturing process is the step by step, individual operations required to make powders into a tablet. Tablets are the solid preparations each containing a single dose of one or more active ingredients and obtained by compressing uniform volume of particles. The manufacturing process is briefly explained as follows:

Dispensing: Dispensing is one of the most important steps in tablet manufacturing process. According to the dosage, raw materials and other ingredients in the mixture are weighed out. Weighing accuracy, moisture, residual solvent content and contamination are issues to be considered during dispensing.

Blending: Blending step in which ingredients mixed together is the most crucial step in the tablet manufacturing process. Because of the different particle size of ingredients, it is difficult to produce homogenous mixture. V types of blender are used during mixing.

Granulation and Milling: Tablet ingredients are completely mixed in this stage. Uniform size granules are created to improve flowability characteristic of initial powder blend. Granulation step is also important before tabletting process. Granulation is crucial for a successful way to do the tabletting step. Wet granulation method is used because of the different particle size. Granules are formed by using granulation liquid. The desired granule size is approximately 0.5 mm.

Drying: This process is important in terms of reducing the residual moisture from granules obtained with the wet granulation. Drying process is carried out with the Turbo-tray dryer.

Compression (Tabletting): Granules are compressed on machines that can produce 16 tablets per rotation. The compression machine used for tabletting has multi-station and high speed tablet presses.

Coating: Tablets are coated after the compression step. Film coating method is used. Here the solution in which contains polymer and solvent is sprayed onto the tablets. The purpose of the coating is as follows:

- To protect raw materials in tablets from moisture and light
- To prolong shelf-life and to provide
- To improve appearance of tablets
- Easier swallow for patients

Flow chart of production process is showed in Figure 1.

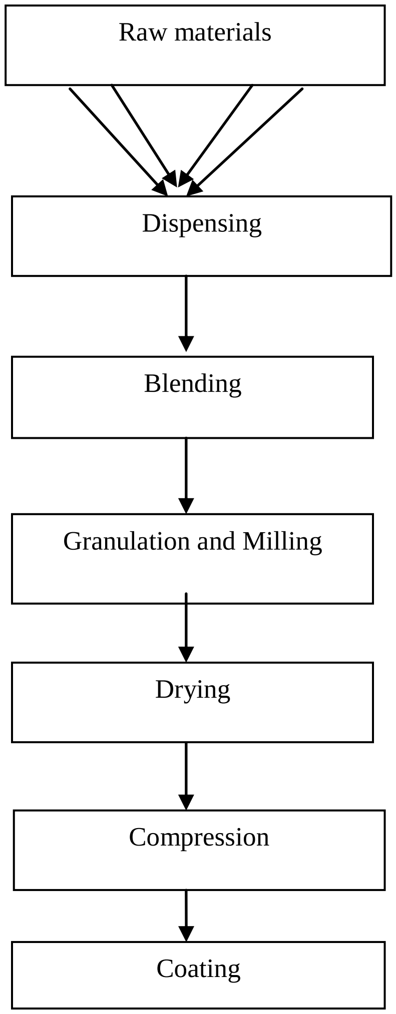

Figure 1. Flow chart of production process

4.1.Quality Control Procedure

Quality control tests have crucial role in pharmaceutical manufacturing, because of this reason numerous controls are carried out all of the manufacturing processes. Quality control procedure is made in three different stages:

- Control of raw materials: All of the raw materials in the tablet are tested to assure that ingredients of the tablet meet specifications and guidelines.

- In-process control: In-process controls enable problem determination at early stage. The quality control staffs carry out various controls at frequent intervals in this stage. Quality control staffs take samples to check for contamination and to ensure that composition is as expected.

- Control of finished product: All the parameters controlled In-process control stage are measured again during production by sampling at hourly intervals.

In-Process and finished product quality control tests for tablets are divided into two groups:

- Official Tests are:

  Weight variation (Uniformity of weight), Disintegration, Dissolution, Drug content.

- Non-Official Tests:

  Hardness, Friability, Thickness.

This study focuses on the weight variation (Uniformity of weight) test of tablets. Tablets are designed to include a certain amount of drug in a certain amount of tablet formula. To understand whether tablets contain correct amount of drug, tablet weight must be periodically measured.

Weight variation test is one of the most important quality tests. This test is done to ensure that, each of tablets includes the correct amount of drug. Also, the aim of the weight variation test is to assure requirements of good manufacturing practices (GMP). Another important point in weight variation test is to reflect variation in the content of active ingredient and appropriate size of the tablets. Besides this, checking the weight variation within a tight range indicates better tablet hardness and friability.

Various assignable causes changed the tablet weight were identified by the quality control staff. These are as follows:

- Tooling of the compression machine
- Machine speed
- Distribution of the granules or particle size distribution
- Poor mixing

United States Pharmacopeia (USP) procedures are followed for all quality test carried out in the laboratory. According to the USP procedures, the weight variation test is described as follows:

- Select 10 or 15 tablets randomly
- Weight tablets individually using analytical balance
- Calculate the average weight
- Compare the individual tablet weights to the average weight
- The percentage deviation of each tablet was calculated by equation (12):

$$Percent\ Difference = \frac{Individual\ \ weight - Average\ \ weight}{Average\ \ weight} x\ 100 \qquad (12)$$

The allowed percent difference as per USP was explained in Table 1.

Table1. Percentage weight deviations

Average weight of tablets	Percent difference
130mg or less	10
More than 130mg through 324mg	7.5
More than 324mg	5

The tablets average weight discussed in our study is 250 mg. Percentage deviation limit allowed by USP shouldn’t exceed ±7.5%. Upper limit and lower limit are calculated by following equations (13) and (14):

Upper limit= Average weight + (Average weight x 7.5%) (13)
Lower limit= Average weight - (Average weight x 7.5%) (14)

Weight of any single tablet is compared with the upper and lower control limit. The tablet meets with the requirement for test approval if no more than two of the any single tablet weights deviate from the average weight by more than ± 7.5% and no tablets deviated by twice ± 7.5%.

In this study, 10 or 15 single tablets are consecutively weighted in one hour. Compression process takes approximately 5 hours. Average weight and percent difference are calculated for every subgroup samples. If average weights and individual weights are comply with the control procedure (MAX 2/10 tablet can be out of 231.25 mg - 268.75 mg limits and 0/10 tablet can't be out of 212.5- 287.5 limits) there is no intervention on the production process; otherwise, it may refer to a deviation or assignable cause on the production process. In this case, compression operation is interrupted, compression stuff and maintenance technician investigate cause of the problem. The problem generally stems from machine compression tools and poor mixing. Necessary settings are carried out by the technician and assignable cause is removed.

According to the data information obtained quality analyst, weight variation characteristic distributes normally with mean μ= 250.8 mg and σ=2.68 mg when the production process is in control. It is proved by means of Kolmogorov-Smirnov test that the data is normally distributed.

4.2. Value of Parameters

Firstly, all parameters should be identified to find the control chart for monitoring economically the process. All parameters were determined by a study carried out with quality manager and quality control analyst. These parameters are explained as follows:

- When the company data is examined, the time between assignable cause occurrences is 18 days. We assume that the production time continuous, occurrence rate of assignable causes 0.0023 for an hour. If we assume the occurrence time follows an exponential distribution, λ =0.0023.
- There are two assignable causes which is detected in compression stage; machine compression tool wear and poor mixing. When data of the company is examined, presence of assignable cause increases mean of weight variation from μ_0=250.8 to μ_1=254.7 ($\mu_1 = \mu_0 + \delta\sigma$). In this case, shift size is~ 1.4 σ.
- The information obtained from the quality analyst, the sampling cost includes two different costs. Cost of sampling (materials cost and labor cost) and cost of sample tablets. The fixed cost (materials cost and labor cost) is predicted to be 1 TRY and the variable cost is estimated to be 0.01 TRY per sample.
- When the process is out of control condition, the amount of nonconforming tablets produced per hour is considered. In this case, average cost for the out of control condition is approximately 35 TRY. Cost for in control condition is neglected.
- Time to sample and chart one item is omitted, because it takes too short, thus T_0=0
- When out of control condition occurs, the entire compressing operation is stopped. Accordingly, d_1=0 and d_2=0.
- When an assignable cause is detected, the compressing machine regulation takes approximately 40 min. (T_r=2/3 hour). Considering the labor cost for maintenance technician and measurement costs, total predicted cost is approximately C_r= 20 TRY.
  Cost of searching for the false alarm and cost of downtime are supposed to two times of C_r , C_f=40 TRY.
- When the old data were analyzed, expected time to detect an assignable cause is approximately 12 min. (T_c=1/5 hour). The required time to detect that the alarm is false is also assumed 12 min. (T_f=1/5 hour).

4.3. Application in R-edcc

In this study, the program is run for three charts most widely used in quality control: CUSUM, EWMA and X-bar charts. Then, the ECH values of three charts are compared. Firstly, the program is run for the the economic design of the X-bar chart. The results are as follows:

```
R> ecoXbar(n = 10:15, lambda = 0.0023, delta = 1.4, C0 = 0, C1 = 35,
+ T0 = 0, Tf = 1/6, Tc = 1/5, Tr = 2/3, d1 = 0, d2 = 0, Cf = 40,
+ Cr = 20, a = 1, b = 0.01, sided = "two")
```

```
$$optimum
 Optimum h  Optimum L  Optimum n        ECH
 5.3395332  3.3584726 15.0000000  0.4883926
```

```
$cost.frame
 Optimum h Optimum L Optimum n       ECH
  5.101656  3.000659        10 0.5193870
  5.166131  3.074774        11 0.5081992
  5.221123  3.147441        12 0.5002306
  5.265931  3.219175        13 0.4946486
  5.305797  3.289225        14 0.4908502
  5.339533  3.358473        15 0.4883926
```

```
$FAR
[1] 0.0001458821
```

```
$ATS
[1] 2.78155
```

FAR shows the false alarm rate when the process is in control condition. It is computed with λ x average number of false alarm.

ATS shows the average time to signal after an assignable cause occured, it is computed with h x ARL2 –τ.

According to the results obtained from the R –edcc, Xbar chart is optimized with the ECH=0.488 when h=5.339, L=3.358 and n=15 are used.

The program is run for economic design of the Cusum chart. The results are as follows:

R> ecoCusum(n = 10:15, lambda = 0.0023, delta = 1.4, C_0 = 0, C_1 = 35,
+ T_0 = 0, T_f = 1/6, Tc = 1/5, Tr = 2/3, d_1 = 0, d_2 = 0, C_f = 40,
+ Cr = 20, a = 1, b = 0.01, sided = "two")

```
$optimum
 Optimum h  Optimum H  Optimum n        ECH
 5.3381113  0.6530528 15.0000000  0.4883345
```

```
$cost.frame
 Optimum h Optimum H Optimum n       ECH
  5.084368 0.8126716        10 0.5184405
  5.155738 0.7714122        11 0.5076628
  5.213518 0.7359087        12 0.4999248
  5.261062 0.7048142        13 0.4944734
  5.301415 0.6775931        14 0.4907495
  5.338111 0.6530528        15 0.4883345
```

```
$FAR
[1] 0.0001436451
```

```
$ATS
[1] 2.781211
```

According to the results obtained from the R –edcc, Cusum chart is optimized with the ECH=0.488 when h=5.338, L=3.358, H=0.653 and n=15 are used.

Lastly, the program is run for economic design of the Ewma chart. The results are as follows:

R>a <- ecoEwma(n = 10:15, w = seq(0.1, 1, by = 0.1), lambda = 0.0023,
+delta = 1.4, C_0 = 0, C_1 =35,T_0 = 0, T_f = 1/6, Tc = 1/5, Tr = 2/3,
+d_1 = 0, d_2 = 0, C_f = 40,Cr = 20, a = 1, b = 0.01, sided = "two")

```
$optimum
 Optimum h  Optimum k  Optimum n  Optimum w       ECH
 5.3395332  3.3584726 15.0000000  1.0000000  0.4883926
```

According to the results obtained from the R –edcc, Ewma chart is optimized with the ECH=0.488 when h=5.339, w=1, k=3.358 and n=15 are used.

There are no differences between charts performance when comparing the ECH values. Additionally, different shift sizes (0.5, 1.0, 1.5 and 2.00) are used to see the sensitivity of charts. The results shows that Cusum charts are more sensitive than the others for the smaller shift size. The program is run for delta=0.5,

```
ecoXbar(n = 10:15, lambda = 0.0021, delta = 0.5, C0 = 0, C1 = 35,
+         T0 = 0, Tf = 1/6, Tc = 1/5, Tr = 2/3, d1 = 0, d2 = 0, Cf = 40,
+         Cr = 20, a = 1, b = 0.01, sided = "two")

$optimum
Optimum h Optimum L Optimum n       ECH
 3.896183  2.213383 15.000000  1.182956

$cost.frame
 Optimum h Optimum L Optimum n      ECH
  3.539549  2.105659        10 1.457329
  3.607517  2.130752        11 1.389527
  3.678430  2.153613        12 1.329276
  3.749240  2.175062        13 1.275369
  3.822437  2.194683        14 1.226851
  3.896183  2.213383        15 1.182956

$FAR
[1] 0.006868635

$ATS
[1] 8.020544


> ecoCusum(n = 10:15, lambda = 0.0021, delta = 0.5, C0 = 0, C1 = 35,
+          T0 = 0, Tf = 1/6, Tc = 1/5, Tr = 2/3, d1 = 0, d2 = 0, Cf = 40,
+          Cr = 20, a = 1, b = 0.01, sided = "two")

$optimum
Optimum h Optimum H Optimum n       ECH
 3.015447  2.004013 15.000000  1.039531

$cost.frame
 Optimum h Optimum H Optimum n      ECH
  2.466753  2.452999        10 1.217496
  2.579361  2.345451        11 1.173445
```

```
 2.689776  2.248426       12 1.134452
 2.798164  2.160642       13 1.099581
 2.906810  2.078946       14 1.068123
 3.015447  2.004013       15 1.039531

$FAR
[1] 0.002896807

$ATS
[1] 6.970298


> ecoEwma(n = 10:15, w = seq(0.1, 1, by = 0.1), lambda = 0.0021,
+       delta = 0.5, C0 = 0, C1 =35,T0 = 0, Tf = 1/6, Tc = 1/5, Tr = 2/3,
+       d1 = 0, d2 = 0, Cf = 40,Cr = 20, a = 1, b = 0.01, sided = "two")

$optimum
Optimum h Optimum k Optimum n Optimum w       ECH
 3.172909  2.504396 15.000000  0.500000  1.041984
```

V. CONCLUSION

This paper contains a real application in a pharmaceutical company. The application is carried out on the tablet production department. The purpose of this study is to determine which chart is more economical for the control of tablet weight. In this study, the software program R-edcc developed by Zu and Park for the economic design of control charts was used. The results show that there is no significant difference between charts performance. Cusum chart performs better than the others for the small changes when the program is run for the different sizes of deviation from the process mean. This study indicates that edcc package is easy to use compared to the other charts design techniques.

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