INTERNATIONAL JOURNAL OF RESEARCH IN COMPUTER APPLICATION & MANAGEMENT

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   RESEARCH METHODOLOGY

   RESULTS & DISCUSSION

   FINDINGS

   RECOMMENDATIONS/SUGGESTIONS

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APPLICATION OF QUALITY CONTROL CHART IN MANUFACTURING INDUSTRIES USING A LOSS FUNCTION APPROACH

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ABSTRACT

The increasing use of Loss Functions in Quality Assurance has created a demand for realistic and representative loss functions. This knowledge is capable of providing alternative strategies for assessing and improving the process performance. This research work is focused on the use of Loss Functions based on the inverted Normal Probability Density Function (INPDF), known as the Inverted Normal Loss Function (INLF) in monitoring the loss of cigarette produced by an International Tobacco Company (ITC). BASIC programming language is used to determine the associated loss due to deviation of the cigarette weight from the target value, varying the maximum loss attainable at each end of the target value. The mean weight of the cigarette is monitored using the $\bar{x}$ and the R charts, which is compared with those of Economic Loss chart varying the loss values. The Conventional chart and the Economic Loss Charts highlight different features of the production process and hence, the economic chart can therefore serve as a compliment to the conventional chart particularly when focusing on the economic aspect.

KEYWORDS

Quality control chart, loss function approach.

INTRODUCTION

LOSS FUNCTION

Loss functions are used in decision theory applications and quality assurance settings, to quantify Losses associated with deviation from a desired target value. In decision theory, an action a and θ of interest, a loss is a function of a parameter and an action. A decision rule d, is a mapping of the range space of the relevant random variable x into the action space a.

$d : R_x \rightarrow a$

Then L (θ,d(X) is random variable and $R(\theta,d) = E_x L(\theta,d(X)) = \int L(\theta,d(x))f(x/\theta)dx$, When X is continuous, it called the risk of using the decision rule d when the true state of nature is θ.

In Quality Assurance setting, Loss Function are used to reflect the economic loss associated with variation about the deviations from the process target of the target value of a product characteristics (Spiring & Yeung, (1998)). In this work we focused on Quality Assurance Settings.

The most common loss function is the quadratic functions corresponding to a Gaussian noise mode with zero means, and a standard deviation that does not depend on the inputs. The Gaussian loss function is used because it has nice analytical properties. However, one of the potential difficulties of the quadratic loss function is that it received large contributions from outliers that have particularly large errors. If there are long tails on the distributions then the solution can be dominated by a very small number of outliers. The techniques that attempt to solve this problem are referred to as robust statistics (Huber, 1972).

Taguchi (1986) used a modified quadratic loss function to assess and illustrate losses associated with deviations of a product characteristics from target. This loss function take the following basic quadratic form $L(X,m)=k(X-m)^2$ where X is a measure of the product characteristics, L is the Loss in monetary terms, m is the point at which the characteristics is actually set, and k is constant that depends on the magnitude of deviation from target.

In response to some criticisms of the quadratic loss functions, Spiring (1993) proposed a loss function based on the inversion of normal probability density function.The resulting inverted Normal Loss Function (INLF) differs from the traditional quadratic loss, in that it is bounded and provides a more reasonable assessment of loss associated with deviation from target. Sun, Laramee and Remberg (1996) improved on the inverted normal loss function (INLF) further.

Chu, Keerth, & Ong (2001) proposed a unified non-quadratic loss function known as soft insensitive loss function (SILF) in solving regression problems. In his submission, obafemi etal (2013) concluded that the expected loss functions will continue to provide insights into optimal process settings and tracking opportunity.

MATERIAL AND METHOD

In Manufacturing, loss functions express the economic consequences associated with deviations from target, since different processes have different sets of economic consequences. A better approach to developing loss functions is therefore desirable.

The quality characteristics of cigarette measured by the quality control department of international Tobacco Company (ITC) are weight, circumference, length and pressure drop. The weight of cigarette here after denoted X, is the focus of this work.

Consider a situation where each stick of cigarette has a target weight of 1000mg. A stick of cigarette must be reprocessed if it is under-weight, while those on target of above the target weight are sent directly to the market. Under-weight therefore attracts more economic loss to the producer than over-weight. The economic loss around the target therefore is asymmetric. There are many types of inverted loss function, which include: inverted gamma loss, inverted normal loss, inverted uniform loss function. However the normal loss function is adopted for this work because the data collected is approximately normal.

GENERAL CLASS OF LOSS FUNCTION

The general class of loss function is based on the inversion of common probability density functions. These classes if loss functions satisfy the criteria that the loss must always be positive, minimum at the target value, monotonically increasing as the process deviates from target and reaches a quantifiable maximum.

Let g (x,T) denote the probability density function (pdf) used in creating the economic loss function for the process and $f(x/\underset{-}{\theta})$ the statistical distribution associated with the process measurements.

$f(x/\underset{-}{\theta})$ where $\underset{-}{\theta}=(\mu,\sigma^2)$ is the statistical distribution of the process under study, which is normally distributed with mean μL and variance σ^2_L. Where μ_L and σ_L refer to the parameter based on the sample taken from the process.

The general form of the inverted probability loss function (IPLF) is defined to be

$$L(x,T) = k\left(1-\frac{g(x,T)}{m}\right) \qquad \forall X \in \Omega ....(1)$$

Where x denotes the process measurement, k the maximum loss, Ω the measurement space and T, the process target. If $f(x/\underset{-}{\theta})$ denotes the probability density function associated with the behavior of process measurement x, the general form of the expected loss function associated with equation (1) will be

$$E(L(x,T)) = \int_\Omega k\left(1-\frac{g(x,T)}{m}\right) f(x/\underset{-}{\theta})dx$$

$$= \int_\Omega k\left(1-\frac{g(x,T)}{m}\right) f(x/\underset{-}{\theta})dx$$

$$= k\left(1-\frac{1}{m}\int_\Omega g(x,T)f(x/\underset{-}{\theta})dx\right)$$

INVERTED NORMAL LOSS FUNCTION

Consider a normal probability density function (pdf) to define g(x,T):

$$g(x,T) = \frac{1}{\sigma_L\sqrt{2\pi}}\exp-\frac{1}{2}\left(\frac{x-T}{\sigma_L}\right) \qquad -\infty < x < \infty,$$

Where T denotes the target and σ_L denotes a scale parameter and the supremum of g (x,T) in this case is $m = \frac{1}{\sigma_L\sqrt{2\pi}}$, achieved where x =T

Since $L(x,T) = k\left(1-\frac{g(x,T)}{m}\right)$, the inverted normal loss function then becomes

$$L(x,T) = k\left(1-\frac{\frac{1}{\sigma_L\sqrt{2\pi}}\exp-\frac{1}{2}\left(\frac{x-T}{\sigma_L}\right)^2}{\frac{1}{\sigma_L\sqrt{2\pi}}}\right)$$

Therefore, L(x, T)=K $L(x,T) = k\left(1-\exp-\frac{1}{2}\left(\frac{x-T}{\sigma_L}\right)^2\right) \qquad -\infty < x < \infty,$

In the case of an asymmetric situation for the general class of loss function

$$L(x,T) = \begin{cases} k_1\left(1-\frac{g(x,T)}{m}\right) & \forall x < T \\ k_2\left(1-\frac{g(x,T)}{m}\right) & \forall x \geq T \end{cases}$$

And for the inverted normal loss with a asymmetric situation

Where k_1, is maximum loss when weight is below the target and k_2 is the maximum loss when weight is above the target

$$L(x,T) = \begin{cases} k_1\left(1-\exp-\frac{1}{2}\left(\frac{x-T}{\sigma_L}\right)^2\right) & \forall x \in (-\infty, T) \\ k_2\left(1-\exp-\frac{1}{2}\left(\frac{x-T}{\sigma_L}\right)^2\right) & \forall x \in (T, \infty) \end{cases}$$

MONITORING THE WEIGHT USING THE CONVENTIONAL AND ECONOMIC LOSS CHARTS

The associated loss due to weight of cigarette is obtained using the inverted normal loss function. The data collected from the process shows that the weights of cigarette follow a normal distribution. The variance and standard deviation are then obtained as follows:

From the data, n = 200, $\sigma^2_{L(n-1)} = 77.469$, $\sigma^2_{L(n-1)} = 8.802$ Since the loss is taken to be asymmetric then,

$$L(x,T) = \begin{cases} k_1\left(1-\exp-\frac{1}{2}\left(\frac{x-1000}{\sigma_L}\right)^2\right) & \forall x \in (-\infty,1000) \\ k_2\left(1-\exp-\frac{1}{2}\left(\frac{x-1000}{\sigma_L}\right)^2\right) & \forall x \in (1000,\infty) \end{cases}$$

Where 1000mg is the target weight set by the organization. The $\bar{X}$ - chart for the weight of cigarette is shown in figure 3.1a and the corresponding R chart show in figure 3.1b.

A BASIC program is used to compute the various values of L(x,T) due to weight of cigarette. The programme is written such that if the value of weight of a cigarette is less than the target value (1000mg), it will use the loss value k_1 and when the value of weight is equal or higher than the target value it will use the loss value k_2 to multiply

$$\left(1-\exp-\frac{1}{2}\left(\frac{x-1000}{\sigma_L}\right)^2\right).$$

The resulting associated loss values and charts obtained with varying values of K_1 and k_2 and their corresponding range chart are shown in the table 3.1.1 to 3.1.3 and figure 3.1 to 3.3b, respectively.

TABLE 3.1.1: WEIGHT OF CIGARETTE IN MG

No.	Weight of cigarette in mg					R
1	985	1000	1003	1015	1008	30
2	1004	1009	1012	1050	1008	46
3	1000	1011	1030	1003	1000	30
4	1002	1008	1009	1003	986	23
5	1011	1025	1009	1008	1008	17
6	1013	1003	986	998	1003	27
7	992	1005	1000	1005	1015	23
8	1003	1004	1013	1008	993	20
9	1005	994	1000	1001	1003	11
10	1005	1012	1016	1006	1013	11
11	1013	1008	1001	1005	1003	12
12	994	1000	1015	1013	1009	21
13	1015	1005	1006	1002	1005	13
14	1001	1008	1001	1010	1012	11
15	994	1001	1011	1010	1008	17
16	1008	1009	1001	1000	1012	12
17	1001	1003	1001	1000	998	5
18	1000	1003	1005	1008	1008	8
19	1008	996	1008	1009	1003	13
20	1000	1003	1008	1001	1003	8

TABLE 3.1.2

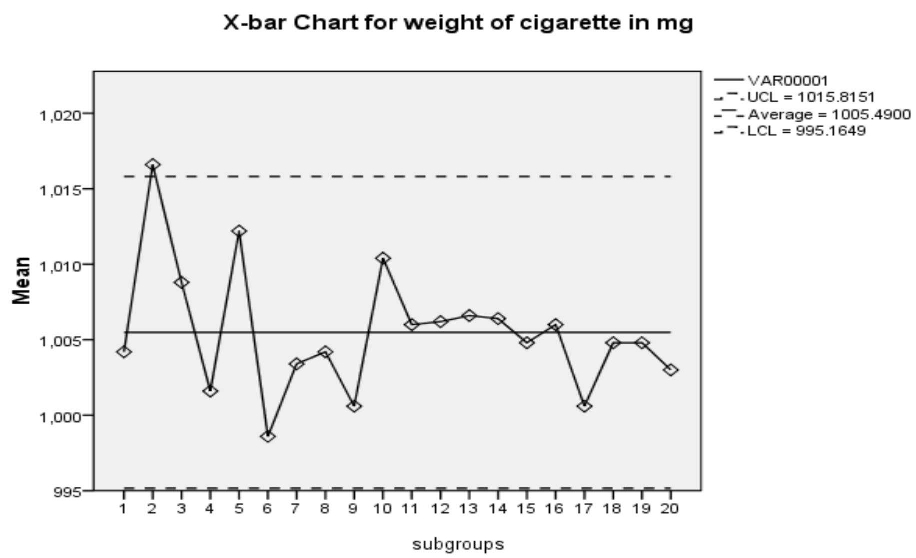
No.	L(,T) with $k_1 = 5$, $k_2 = 2$					R
1	3.83	.00	.11	1.53	.68	3.83
2	.20	.81	1.21	2.00	.68	1.80
3	.00	1.08	1.99	.11	.68	1.99
4	.05	.68	.81	.11	3.59	3.54
5	1.08	1.96	.81	.41	.68	1.55
6	1.33	.11	3.59	3.03	.11	3.48
7	1.70	.54	.00	.30	1.53	1.70
8	.11	.20	1.33	.68	1.36	1.25
9	.30	1.04	.01	.01	.11	1.03
10	.30	1.21	1.61	.41	1.33	1.30
11	1.33	.68	.01	.30	.11	1.32
12	1.04	.00	1.53	1.33	.81	1.53
13	1.53	.30	.41	.05	.30	1.48
14	.01	.68	.01	.95	1.21	1.20
15	1.04	.01	1.08	.95	.68	1.07
16	.68	.81	.01	.00	1.21	1.21
17	.01	.11	.01	.00	.13	.13
18	.00	.11	.30	.68	.68	.68
19	.68	.49	.68	.81	.11	.70
20	.00	.11	.68	.01	.11	.68

TABLE 3.1.3

No.	L(,T) with $k_1 = 4$, $k_2 = 1$					R
1	3.06	.00	.06	.77	.34	3.06
2	.10	.41	.61	1.00	.34	.90
3	.00	.54	1.00	.06	.34	1.00
4	.03	.34	.41	.06	2.87	2.84
5	.54	.98	.41	.34	.34	.64
6	.66	.06	2.87	2.42	.56	2.81
7	1.35	.15	.00	.15	.77	1.35
8	.06	.10	.66	.34	1.08	1.02
9	.15	.83	.00	.01	.06	.83
10	.15	.61	.81	.21	.66	.66
11	.66	.34	.01	.15	.06	.65
12	.83	.00	.77	.66	.41	.77
13	.77	.15	.21	.03	.15	.74
14	.01	.34	.01	.48	.61	.60
15	.83	.01	.54	.48	.34	.82
16	.34	.41	.01	.00	.61	.61
17	.01	.06	.01	.00	.10	.10
18	.00	.06	.15	.34	.34	.34
19	.34	.39	.34	.41	.06	.35
20	.00	.06	.34	.01	.06	.34

For each of the table, as expected the associated loss values for varying value of k_1 and k_2 increases as deviation increases from the target value.

FIG. 3.1



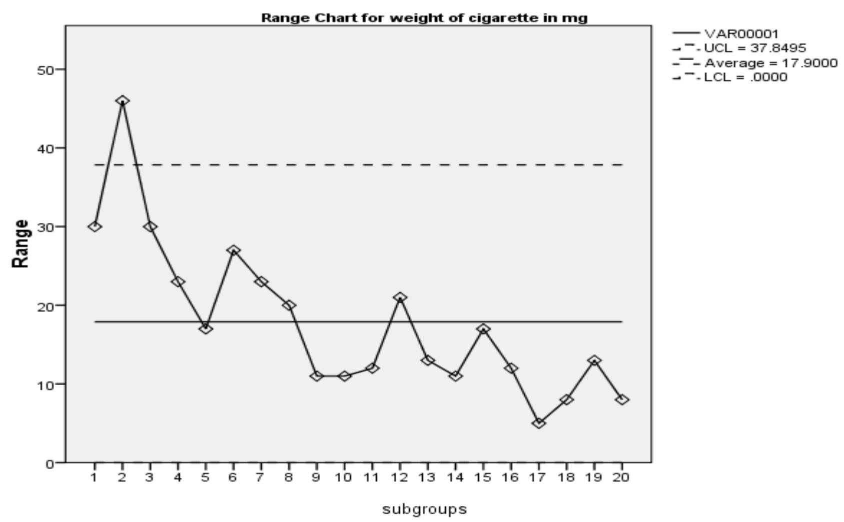
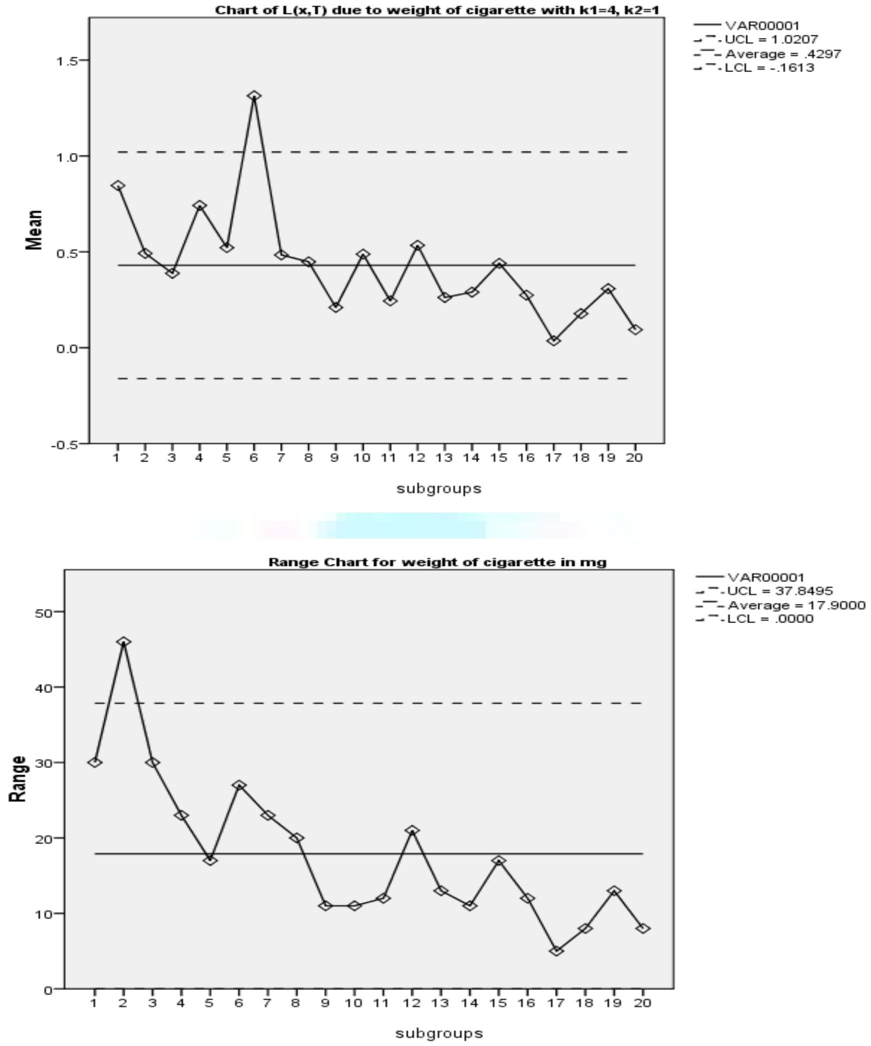


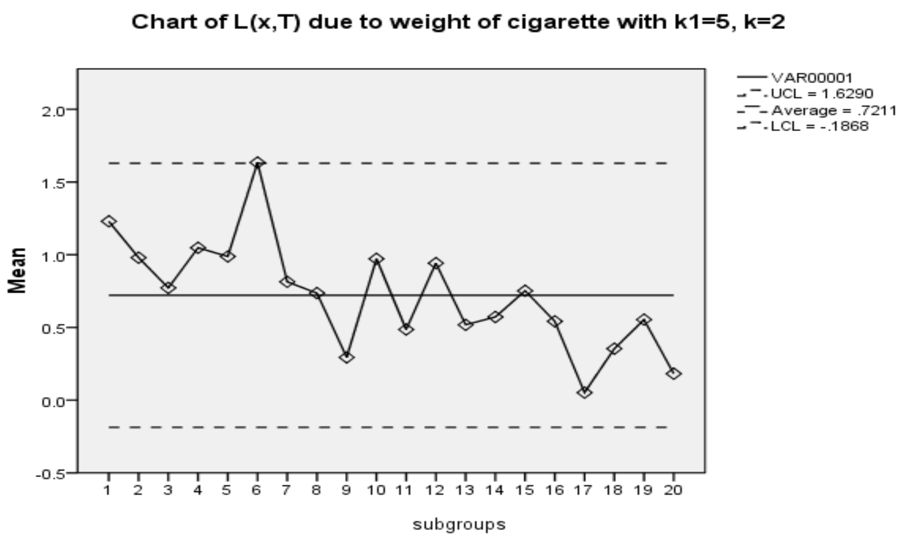
figure 3.1, above shows the $\bar{X}$ - chart of the weight of cigarette, the second sample point falls outside the upper control limit, which is also the case for its corresponding range chart in figure 3.1b above. There is then an indication that the weight of cigarette is out of control.

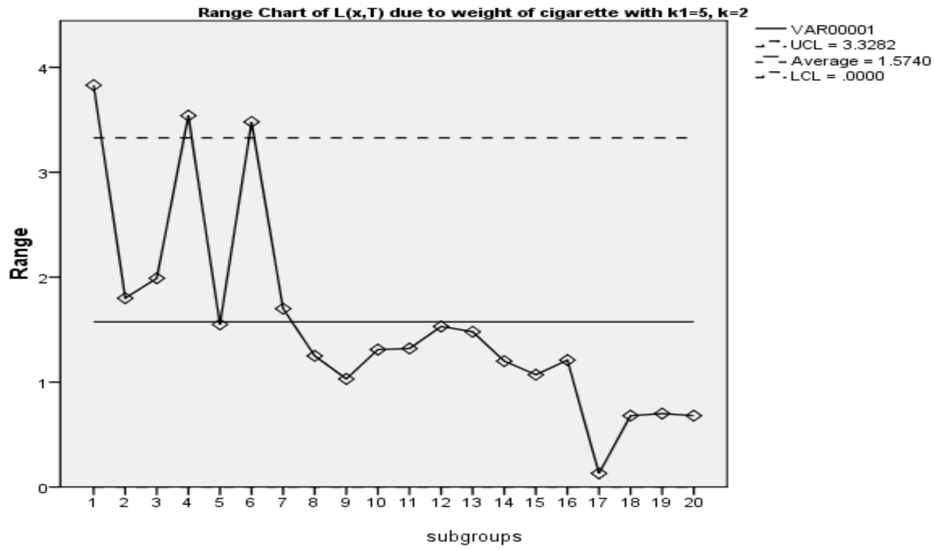
FIG. 3.2



The economic loss chart (L(x,T)due to weight of cigarette for k_1=4 and k_2 = 1 in figure 3.2a show that the sixth sample point is out of upper control limit which is an indication that the process is out-of-control. Also its corresponding range chart in figure 3.2b has the first, the fourth and sixth sample points out of the upper control limit, which is an indication that the process loss is out – of – control.

FIG 3.3





The economic loss chart due to weight of cigarette with maximum loss value k_1=5 and k_2 = 2 as show in figure 3.3a is out of control as one of the points is outside the control limits. The corresponding range chart in figure 3.3b also shows an out – of – control state. As three points fall outside the control limits.

SUMMARY OF RESULT

The economic loss associated with the weight of cigarette as obtained in this work has its loss values positive, minimum at the target value and increase proportionally with deviation of weight from the target value, as expected. Hence the inverted Normal Loss Function (INLF) satisfies the criteria of the loss associated to a product characteristic.

The $\bar{X}$ - chart and its corresponding range chart for the weight of cigarette shows an out-of control state. The economic loss chart with k_1=4 and k_2 = 1 and k_1=5 and k_2 = 2 with their corresponding range charts shows an out-control states of the process loss respectively.

CONCLUSION

The conventional control chart for the weight of cigarette and that of the associated economic loss charts highlight different features of the process. While the conventional control chart monitor the weight of cigarette manufactured the economic loss charts monitor the associated loss due to weight of cigarrette i.e. the economic consequences of the company. Since the economic loss and range charts for various values of k_1 and k_2 do not all follow the same pattern as the conventional charts; that is some charts are not indicating an out of control state while some other do stresses the fact that they may not be performing the same function absolutely.

Also for the facts that shift in process mean may be inevitable, the use of economic loss will go a long way in setting the process optimally.

Based on the results arrived at on this research works, the inverted normal loss function (INLF) provides practitioners with loss function that can accurately reflects process loss and the economic chart has the benefit of providing added economic loss performance of the company understood by the management. Adoption of the economic loss chart is therefore recommended to compliment the conventional control chart.

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