

Assessment of Process Capability: the case of Soft Drinks Processing Unit

Kottala Sri Yogi *

Department of Industrial & Production Engineering Institute of Technology,
Guru Ghasidas Vishwavidyalaya (A *Central University*), Bilaspur 495009,
Chhattisgarh, India.

*Corresponding author: kottalasriyogi@gmail.com

Abstract. The process capability studies have significant impact in investigating process variation which is important in achieving product quality characteristics. Its indices are to measure the inherent variability of a process and thus to improve the process performance radically. The main objective of this paper is to understand capability of the process being produced within specification of the soft drinks processing unit, a premier brands being marketed in India. A few selected critical parameters in soft drinks processing: concentration of gas volume, concentration of brix, torque of crock has been considered for this study. Assessed some relevant statistical parameters: short term capability, long term capability as a process capability indices perspective. For assessment we have used real time data of soft drinks bottling company which is located in state of Chhattisgarh, India. As our research output suggested reasons for variations in the process which is validated using ANOVA and also predicted Taguchi cost function, assessed also predicted waste monetarily this shall be used by organization for improving process parameters. This research work has substantially benefitted the organization in understanding the various variations of selected critical parameters for achieving zero rejection.

1. Introduction

Process capability studies are being incorporated as a successful quality improvement strategic tool in achieving customer satisfaction. Process capability analysis (PCA) and Six Sigma methodology occupy important places in quality and process improvement initiatives. As a fundamental technique in any production, quality and process improvement efforts, PCA is used to improve processes, products or services to achieve higher levels of customer satisfaction.

Process refers to some unique combination of machine, tool, method, materials, and people engaged in production. It is often feasible and illuminating to separate and quantify the effect of the variables entering this combination. Capability refers to ability, based on tested performance; to achieve measurable result. Inherent capability refers to the product uniformity resulting from a process that is in a state of statistical control. The product is measured because product variation is the end result.

1.1 Significance of “capability of processes”

Process capability measurements allow us to summarize process capability in terms of meaningful percentages and metrics. To predict the extent to which the process will be able to hold tolerance or



customer requirements. It helps you choose from among competing processes, the most appropriate one for meeting customers' expectation. Knowing the capability of processes, we can specify better the quality performance requirements for new machines, parts and processes. Process capability is the long-term performance level of the process after it has been brought under statistical control. In other words, process capability is the range over which the natural variation of the process occurs as determined by the system of common causes. Process capability is also the ability of the combination of people, machine, methods, material, and measurements to produce a product that will consistently meet the design requirements or customer expectation.

1.2 Research Objectives

- i. To evaluate process control limits & actual process capability indices.
- ii. To assess long term and short term process capability for the process.
- iii. To evaluate the Taguchi's loss function of the process for considered parameters i.e gas volume, brix and torque.

2. LITERATURE REVIEW

For assessing the process capability indices for soft drinks processing unit. The review considered the most cited academic publications covering various journals viz., quality engineering, communication in statistics- Simulation & Computation, Journal of statistical computation & simulation, Communication in statistics - Theory & methods, International journal of production research and Journal of applied statistics. Regarding process capability indices used in various processes, in manufacturing different products. The Boolean keyword combination "(Process Capability or Statistical processes, SPC, SQC,) AND (Soft drinks or food processing)" was applied to conduct the literature search. Keywords such as Process Capability, PCI, Soft drinks, Process capability studies in Indian Soft drinks, were used to search the databases.

Author (s)	Findings/Significant Contribution
Chen et al., (2017) [1]	An economic of line inspection/disposition approach is proposed, which incorporates manufacturing variation.
Djauhari et al., (2016)[2]	Method in designing reliable control charts, when observed sensitivity to the change in variance for small or moderate correlation is present, which provides a root, causes analysis of an out of control signal.
Maman et al., (2016) [3]	Observed the optimal sample size required to achieve a desired error of estimation using absolute percentage error of different Cp estimates.
Saleh et al., (2016) [4]	Designed the CUSUM chart, observed in-control ARL exceeds a desired value with a specified probability. Using a bootstrap-based design technique adjusted the control limits.
Ganji & Gildeh (2016)[5]	Introduced a new class of indices, $C_p^m(u,v)$ for the processes with asymmetric tolerance. Observed the relation between this index and the departure ratio of the process centering, as well as, the relation between this index and the upper bound of the percentage of non-conforming products.
Ali & Riaz (2014) [6]	Studied the generalized capability indices from the Bayesian view point under different symmetric and asymmetric loss functions for the simple and mixture of generalized life time models.

Author (s)	Findings/Significant Contribution
Chen & Tsai (2012) [7]	Density function of the natural estimator is derived. The expression is in terms of finite sum and only involves standard normal distribution. Four ensemble estimators for C_{pk} are proposed.
Hussein et al., (2012) [8]	Proposed a sequential procedure for testing whether two processes are equally capable by using the PCI (C_{pm}).
Niavarani et al., (2012) [9]	Three indices referred to as NC_{pM} , MC_{pM} , and NMC_{pM} in order to evaluate process capability in multivariate environment.
Daniel Grau (2010) [10]	New PCIs proposed based on empirical percentiles, asymmetry of the tolerances as well as the asymmetry of the process distribution has been considered.
Perakis (2010) [11]	The estimation of the difference between the values of process capability indices C_{pm} or C_{pmk} for two processes is considered. Point estimators of such types of differences are defined, separately for each of the two indices, and their distributional properties are investigated.
Parchami & Mashinchi (2010) [12]	Similar to the traditional process capability indices (PCIs), we develop a fuzzy analogue by a distance defined on a fuzzy limit space and introduce PCIs, where instead of precise SLs we have two membership functions for upper and lower SLs.
Jeang (2010) [13]	Proposed process capability expression revised from the conventional C_{pm} in consideration of the balance between tolerance cost and quality loss has been developed.
Wei Wu & Huang (2010) [14]	Investigated the concept of generalized pivotal quantities to derive the generalized confidence intervals (GCI) for the capability ratio and the capability difference between two given suppliers.
Albing & Vännman (2009) [15]	Investigated a new class of process capability indices for target value 0. Two estimators of the proposed index are studied and the asymptotic distributions of these estimators are derived.
Khadse & Shinde (2009) [16]	Computing aspects of proposed PCIs are discussed for normal and non normal processes when process tolerance is symmetric as well as asymmetric.
Lovelace & Swain (2009) [17]	Proposed process capability index estimation methodology for C_p and C_{pk} for the case of non-normal, zero-bound process data using the delta distribution, a variant of the log normal distribution.
Mannar & Ceglarek (2009) [18]	Introduced a methodology for functional capability analysis and optimal process adjustment for products with failures that occur when design parameters and process variables are within tolerance limits (in-specs).
Chen et al., (2008) [19]	Evaluated the capabilities of multi process products together with nominal-the-best specifications, larger-the-better and smaller-the-better specifications. Proposed process capability analysis chart ($PCAC/C_{pm}$), process capability analysis chart ($PCAC/C_{pk}$) to consider process yield and expected process loss.
Saxena & Singh (2006) [20]	Studied a class of shrinkage estimators for C_p when a prior guessed value, the Bayesian estimation of C_p has been done under squared error loss function by assuming quasi-prior distributions of sigma and $1/\sigma$.
Pearn et al., (2005) [21]	Sensitivity investigation on process capability C_p and C_{pm} in the presence of gauge measurement errors.
Pal (2004) [22]	Outlined the procedure using the generalized lambda distribution (GLD) curve for modelling a set of process data and for estimating percentile Points in order to compute generalized PCIs.

Author (s)	Findings/Significant Contribution
Lee Ho & Quinino (2003) [23]	Proposed a procedure that minimizes losses by adjusting the process mean in an economical way. Developed a program that allows the user to find the optimum mean value easily.
Perakis & Xekalaki (2003) [24]	New index that is a variant of C_{pm} is introduced proposed index performs satisfactorily for processes with symmetric or asymmetric specifications.
Flaig (2002) [25]	Presented a multiple objective approach to process capability optimization, that identifies the key input and output variables, and found a mean shift and variation change that optimizes profitability.
Nam et al.,(2002) [26]	Asymptotic variances of capability indices have been used to derive associated percentile-t boot strap confidence intervals and compared percentile-t bootstrap confidence intervals with Franklin & Wasserman' s standard.
Richard et al.,(2002) [27]	Proposed multistage process capability analysis algorithm demonstrated with two 2- stage industrial process examples and a 4-stage process example for its expandability.
Zhang & Ni (2002) [28]	Introduced and investigated the new PCIs index that has direct quantitative association with the probability or the proportion of the conforming process output.
Chen et al., (2001) [29]	Developed one process capability analysis chart (PCAC) for precise measurement of an entire product composed of symmetric tolerances, asymmetric tolerances, larger-the-better and smaller-the-better characteristics.
Hsin-Hung Wu & Swain (2001) [30]	Presented two families of non-normal PCIs observed in the literature, to evaluate how the families of non-normal PCIs perform for non-Non processes using simulation.
Niverthi & Dey (2000) [31]	Examined the multivariate versions of the common process capability indices (PCI's) denoted by C_p , and C_{pk} Markov chain Monte Carlo (MCMC) methods are used to generate sampling distributions for the various PCI's.
Wah Lai & Chew (2000) [32]	Studied gauge repeatability and reproducibility (GRR) applied a non parametric method.
Asokan & Unnithan (1999) [33]	Proposed a procedure for estimating the mean and standard deviation of a process from a sample of a lot truncated at its specifications.
Wen & Mergen (1999) [34]	Investigated finding the best location for the process mean for a situation where the process is stable but not capable of meeting the specification limits.
Alan Veevers (1998) [35]	The multivariate viability index V_m is defined, discussed and illustrated using an example from the minerals sector.
Pearn (1998) [36]	Introduced a new index C''_{pk} , which is shown to be superior to the existing generalizations of C_{pk} investigated the statistical properties of the natural estimator of C''_{pk} , assuming that the process is normally distributed.
Chen (1997) [37]	Study of asymptotic behavior the asymptotic distributions of the estimators of a rather wide class of PCI's are investigated in a unified approach.
Levinson (1997) [38]	Used the non central t distribution to get exact confidence limit. Also discussed simple approximations for the confidence limits.
Pearn & Chang (1997) [39]	Extended Wright's simulation study to cover some skewed distributions including chi-square, lognormal, and Weibull distributions for some parameter values. Found that the percentage bias of the estimator increases as the skewness coefficient $ \mu_3/\sigma^3 $ increases.

Encapsulating the literature review it has been observed that researchers used different methodologies to understand/evaluate process capability indices. Some researchers modified existing methods,

existing plotting techniques of control charts to interpret the process capability studies as well as various statistical parameters more clearly. To make more clear description, researchers focused on optimal sample size for error approximation, relation between index and departure ratio, capability indices in Bayesian view, PCIs based on empirical percentiles, point estimators of differences while PCI calculation, fuzzy analogue application for PCI, new methodology for functional capability analysis, sensitivity investigation on PCI, multistage process capability analysis algorithm, multivariate versions of common process capability indices, asymptotic behaviour and asymptotic distributions of the estimators and simulation studies on PCI.

3. SOFT DRINKS INDUSTRY IN INDIA

Pepsi and Coca-Cola are the leading major players in carbonated drinks in the Indian market. The Carbonated drinks are dominated by artificial flavours based on cola, orange and limes. Major ingredients of drink are based on artificial flavours and sweetening agents as no other natural juice is used. Sixty two percent of the total soft drinks market is cola products. Based on NCAER survey, some of the statistical facts are 91% of soft drink industry in the country is in the lower, lower middle and upper middle class people. Potential growth rate of 10 - 15 % in monetary value, 20-22 % in volume value.[40]

Economic view of Indian Soft drink market best quoted as Duopoly by two major players Coke and Pepsi and both players having concrete monopoly power over the Indian Consumer. Soft drinks have a fairly high price elasticity of demand in which price and sales volume are have been balanced as a major performance indicator among producers. Pricing strategies of both companies is similar and try to gain market share by innovative promotional activities using celebrities as brand ambassadors. Estimated market of 284 million per year of the total soft drink (carbonated beverages and juices). The market follows one of the TCSR of forecasting model i.e is highly seasonal in nature with consumption varying from 25 million crates per month during peak season to 15 million during off-season. The buying behavior of urban population have significant role as major market is predominantly urban with 25 per cent contribution from rural areas. Mineral water market in India is 65 million crates. On an average, the monthly consumption is estimated at 4.9 million crates, which increase to 5.2 million during peak season.

3.1 *The Indian Beverage Market*

India's one billion people, growing middle class, and low per capita consumption of soft drinks made it a highly contested prize in the global CSD market in the early twenty-first century. Coke and Pepsi dominated the market and together had a consolidated market share above 95%. While soft drinks were once considered products only for the affluent, by 2003 91% of sales were made to the lower, middle and upper middle classes. Soft drink sales in India grew 76% between 1998 and 2002, from 5,670 million bottles to over 10,000 million and were expected to grow at least 10% per year through 2012. In spite of this growth, annual per capita consumption was only 6 bottles versus 17 in Pakistan, 73 in Thailand, 173 in the Philippines and 800 in the United States With its large population and low consumption, the rural market represented a significant opportunity for penetration and a critical battleground for market dominance.

4. METHODOLOGY

4.1 *About the Company*

Established in 1992 Ltd company initially started production for Parle Soft Drinks the plant located in the state of Chhattisgarh, India. ABCD Ltd¹. It is basically a Franchisee owned Bottling Operation unit

¹ Name of original bottling unit has been changed to ABCD Ltd., to avoid conflict of Interest.

(FOBO) of premier soft drink (Gama)² available globally and also market leader of soft drink in India. This bottling company serves the market of Chhattisgarh as marketing execution strategy. ABCD only executes marketing strategies planned by Gama India for its operational area. It has limited freedom for promotional activities for which it has to get approval from Gama India. ABCD Ltd works on target basis it gets target by Coca Cola India (CCI) based on its previous performance in terms of cases to be sold and on that it received material for manufacturing the CCI beverages. Production Capacity: ABCD Ltd is presently producing 4 million cases (RGB + PET) annually. ABCD Ltd production capability can be viewed in the following table:

Type	No. Of bottles per minute (bpm)
RGB (Recyclable Glass Bottle)	532
PET	60
KMW (Kinley Mineral Water)	60

Thus ABCD Ltd enjoys producing all Carbonated Soft Drinks (CSD) brands and mineral water offered by CCI which are Coke, Thumsup, Limca, Fanta, Sprite, Kinley water and Kinley soda in different packages viz. RGB in 200ml-300ml, PET in 600ml, 1.25lit, and 2lit and for Kinley water it's PET in 1lit and 500ml and Kinley soda in 300ml RGB, 600ml PET.

4.2 About the soft drink processes.

Production process is done in two different sections based on types of bottles i.e PET bottling and RGB bottling. PET bottles are formed from the pre-forms of the material Poly Ethylene Terephthalate. RGB is elaborated as Returnable Glass Bottles. These empty bottles are returned from the market and reused after processing. In this current study we have considered only bottling process of PET type. In PET line, bottles are made from preforms which are tested before use. In preform testing, height, weight, polarization are checked according to Coca Cola India standards. For 600 ml PET bottle dimensions are Weight = 25.7 gm., Height = 96.78 gm.

4.2.1 PET Blowing process & filling of PET bottle flow

PET blowing process consists of thirteen steps as follows:

- Step: 1 preform issue from store
- Step :2 transfer of preform from store to blowing room
- Step :3 preform storage in blowing room or day storage
- Step :4 preform uploading in the hopper by the preform
- Step :5 filter from jumbo carton
- Step :6 preform through the elevator
- Step :7 preform conveyed through conveyor
- Step :8 heating of preform
- Step :9 blowing Machine (SIPA)[air pressure= 40nbars, temp = 90-110° c]
- Step :10 checking blown Bottle Specification
- Step :11 air Flow through Air filter
- Step :12 conveyed to filler
- Step :13 rinsing with 1-3ppm Cl₂ in soft water & pressure = 1.5kg/cm²

Filling process consists of nineteen steps as follows:

- Step: 1 Treated water intake in deaeration tank
- Step: 2 syrup intake in the syrup tank of paramix

² Name of original company has been changed to GAMA to avoid conflict of Interest.

Step: 3 mix inline through V-10 proportioning valve
 Step: 4 beverage for chilling through PHE
 Step: 5 injection of CO₂
 Step: 6 beverage in the buffer tank
 Step: 7 proportioning of treated water, syrup & CO₂ (chilling, carbonating, mixing temp. = 7°C)
 Step: 8 counter pressure filler
 Step: 9 filling
 Step: 10 closure - elevator closure - capping of filled bottle
 Step: 11 checking of filled bottle torque (5-17Psi)
 Step: 12 warmer temperature [38 - 42°C]
 Step: 13 labeling
 Step: 14 data loading
 Step: 15 filled bottle inspection - removal of half filled and defect bottle
 Step: 16 corrugated pad - shrink wrapping [temp. 150-160°C]
 Step: 17 secondary coding on HDPE layer
 Step: 18 storage of finished product
 Step: 19 dispatch
 Through this process PET bottles will be ready for the filling of beverage.

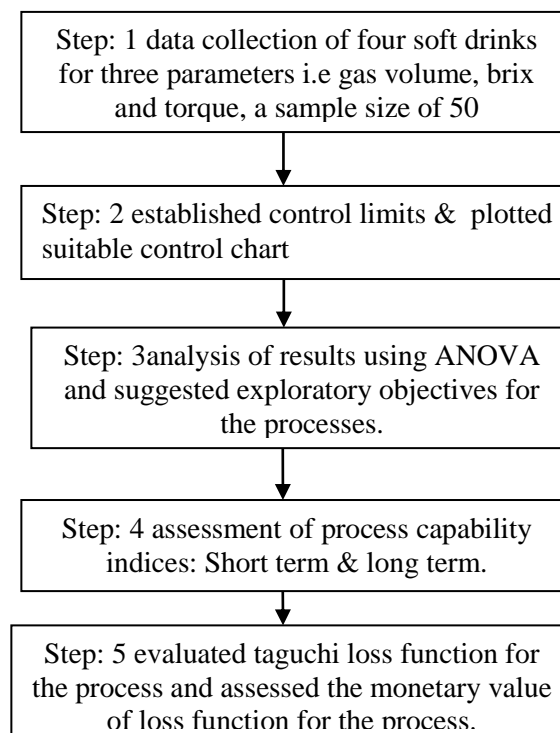


Figure 1. Methodology adopted for the current study (Source: Author, 2017)

From figure 1. methodology adopted for current study in accomplishing the research objectives step by step with statistical inferences as well as operational views as statistical process control aspect.

5. RESULTS AND DISCUSSION

This section discusses first relevant statistical parameters for four soft drinks, ANOVA results for sample observations for four soft drinks with statistical inferences followed by relevant control charts

with interpretation is also discussed, and interpretation of assessment of process capability indices: Short term and long term finally evaluated taguchi loss function monetary values of four soft drinks for three technical parameters i.e gas volume, brix and torque are discussed.

Table 1. ANOVA two way testing results on observations for four different soft drinks

Parameter	F _{actual}	P-Value	F _{Critical}
Gas volume	1.5348	0.015	1.48
Brix	1.7374	0.007	1.36
Torque	1.5177	0.017	1.47

From table 9 ANOVA two way results without replication has been tested on the data /sample of observations to find any difference statistically of on four soft drinks viz ., Limca, Sprite, Thumsup and Fanta using the parameters selected i.e gas volume, brix and torque for the current study. It has been observed that there is a huge difference in their means observations as condition: $F_{\text{actual}} > F_{\text{Critical}}$ is fulfilled with p-value less 0.05.

Table 2. Statistical process control specifications of LIMCA

	Gas Volume	BRIX	TORQUE
USL	4.4233	10.6039	12.4140
LSL	4.3955	10.5705	10.0940
PCI	1.0000	1.0000	1.0000
Mean	4.4094	10.5872	11.2540

Using statistical parameters i.e Upper Specification limit (USL), lower specification limit (LSL) process Capability index (PCI) and Mean, from table. 2 plotted the control charts which are shown in figure 2, figure 3 and figure 4.

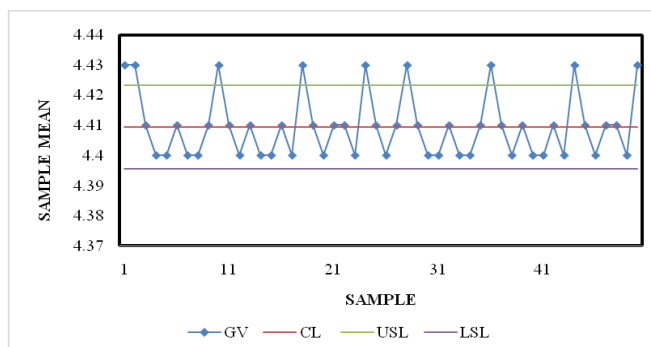


Figure 2. LIMCA's Control Chart for Gas volume

From figure 2. the process is stable and in control satisfactorily, it has been observed that twenty one points just above the Lower control limit and nine point are just below the upper control limit this signifies that probably process has process variation has been dramatically reduced might look like "too good to be true" or "do not touch the process" and remaining points are on central line which is desirable. In contrast we might see this pattern on process if one or various nozzles become clogged. It is important to analyze the desirability of such change.

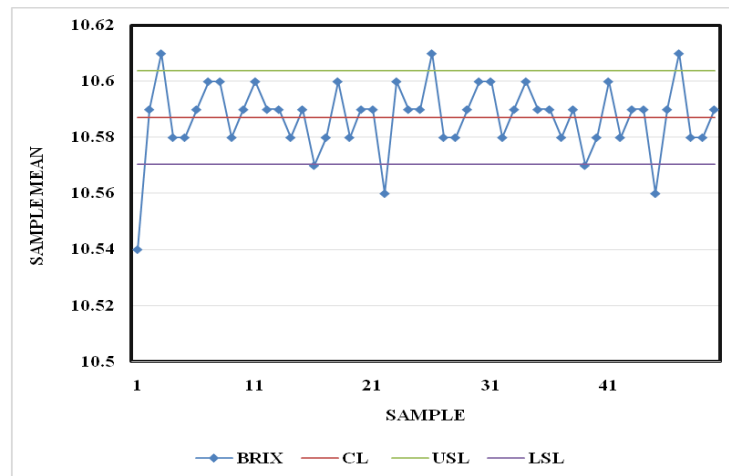


Figure 3. LIMCA's Control Chart for BRIX

Similarly from figure. 3 the process is stable and in control, however this is uncommon pattern. This can be caused by over adjustment of the equipment of the equipment, special attention must be given to data integrity.

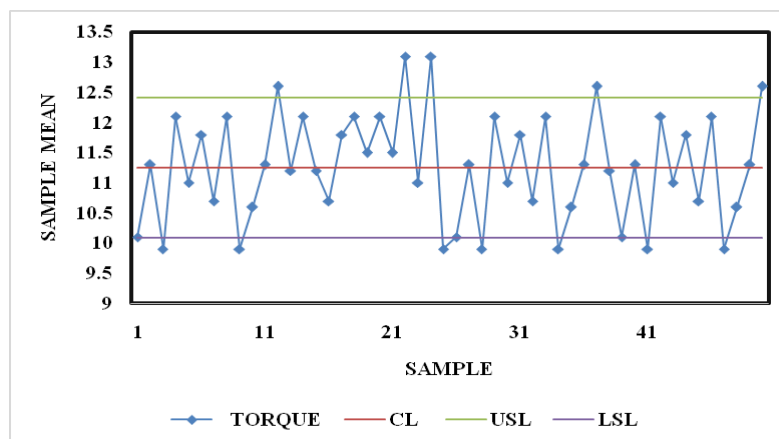


Figure 4. LIMCA's Control Chart for TORQUE

From figure 4. all points either increasing or decreasing this might be an indication of tool wear, machine deterioration, tired operator, and so on. It does not represent a sudden change in the process. However, process is in control and all the points are within the control limit.

Table 3. Statistical process control specifications of Sprite

Specifications	Gas Volume	BRIX	TORQUE
USL	4.4284	11.7812	13.0371
LSL	4.3972	11.7604	10.6389
PCI	1.0000	1.0000	1.0000
Mean	4.4128	11.7708	11.8380

Using statistical parameters i.e Upper Specification limit (USL), lower specification limit (LSL) process capability index (PCI) and Mean, from table. 3 plotted the control charts which are shown in figure 5, figure 6 and figure 7.

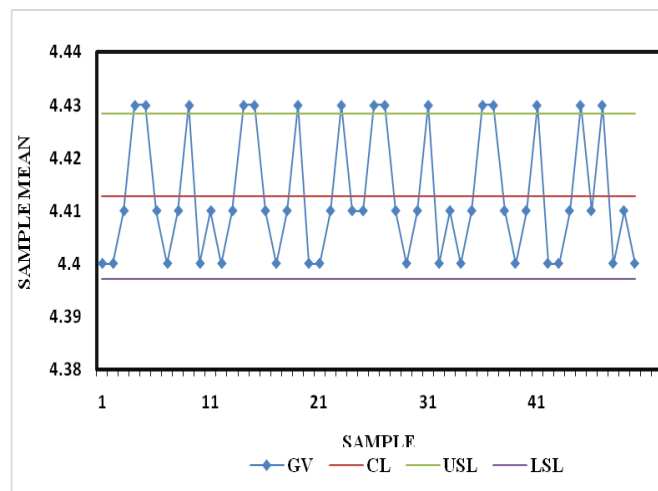


Figure 5. SPRITE's Control chart for Gas volume

From figure 5, fifteen points near the upper control line and sixteen points just above the upper control line. This is uncommon pattern. This can be caused by over adjustment. However, the process is under control as well as stable.

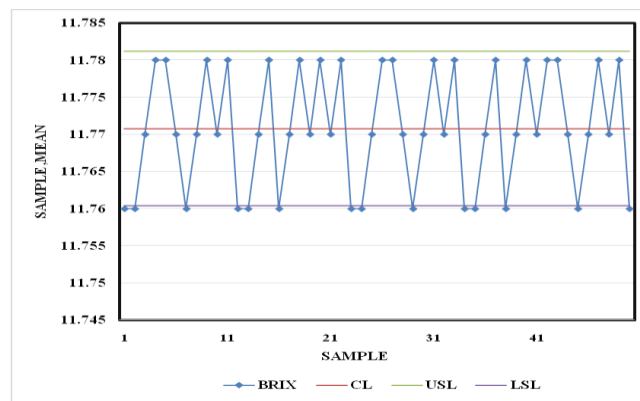


Figure 6. SPRITE's Control chart for BRIX

From figure 6 eighteen points near the upper control line and fourteen points just above the lower control line which is similar to previous case in figure 4. This is uncommon pattern. This can be caused by over adjustment. However, the process is under control as well as stable.

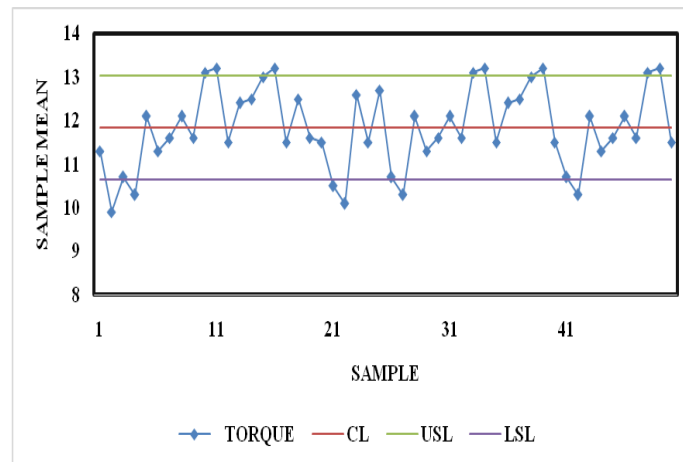


Figure 7. SPRITE's Control chart for TORQUE

From figure 7, all points either increasing or decreasing (erratic behaviour pattern) this might be an indication of tool wear, machine deterioration, tired operator, and so on. It does not represent a sudden change in the process. However, process is in control and all the points are within the control limit.

Table 4. Statistical process control specifications of Thumsup

Specifications	Gas volume	Brix	Torque
USL	4.4379	10.2060	12.2997
LSL	4.3793	10.1832	10.2775
PCI	1.0000	1.0000	1.0000
MEAN	4.4086	10.1946	11.2886

Using statistical parameters i.e Upper Specification limit (USL), lower specification limit (LSL) process Capability index (PCI) and Mean, from table. 4 plotted the control charts which are shown in figure 7, figure 8 and figure 9.

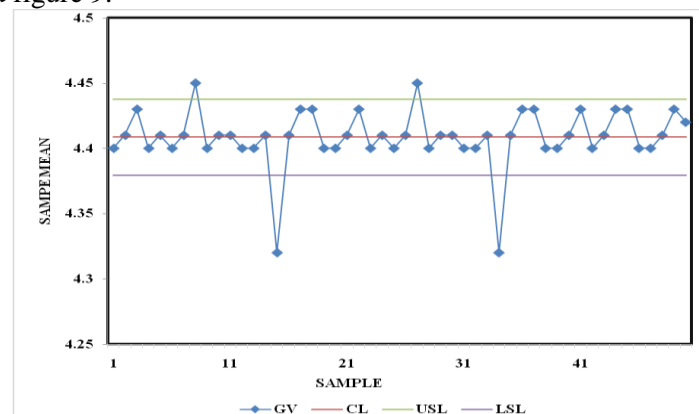


Figure 8. Thumsup's control chart for gas volume

From figure 8, seventeen points on central line, eighteen points are just below central line, two points are just above lower control limit, two points are above upper control limit, process is not under control, and this is usually the result of a change in the process centering. Although the process variation might have remained constant, the process has shifted toward one of the control limits. This type of pattern does not mean something bad has happened. However, all other points are in control,

in this particular case, when excluded the sample data points which are out of control and re-calculated the control limits in which the process is in control.

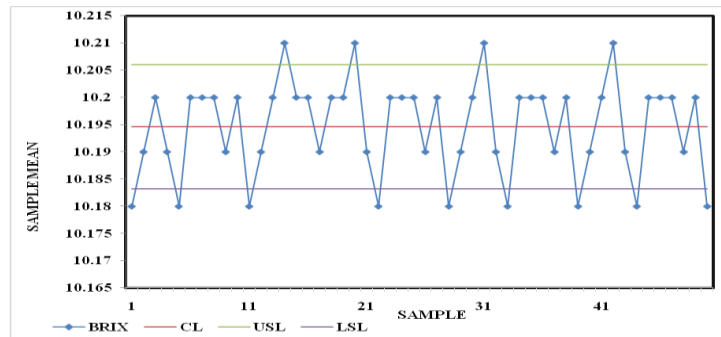


Figure 9. Thumsup's control chart for brix

Figure.9 nine points just above lower control limit and four points are just near the upper control line, thirteen points are just below central line, twenty four points are median of upper control limit and central line. Usually the result of a change in the process centering. Although the process variation might have remained constant, the process has shifted toward one of the control limits. This type of pattern does not mean something bad has happened. However, process is in control.

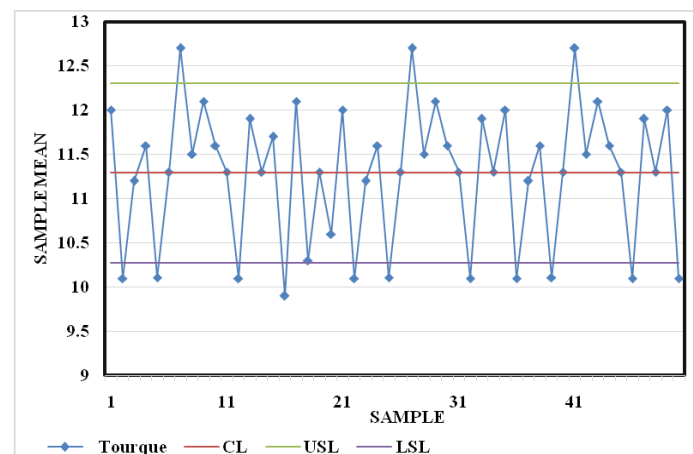


Figure 10. Thumsup's Control chart for Torque

From figure 10, ten points are on central line, ten points are just above central line, three points are out of upper control limit and one point is out of lower control limit, excluding the points that have fallen out of control re calculated the new control limits, resulted process is under control. This pattern might be indicative of a sudden increase in the process variation. It is possible to have some points in this zone from time to time, but two out of three consecutive points is not desirable.

Table 5. Statistical process control specifications of Fanta

Specifications	Gas Volume	Brix	Torque
USL	2.8413	13.2674	12.5022
LSL	2.7787	13.2446	9.9718
PCI	0.0625	0.0227	2.5303
MEAN	2.8100	13.2560	11.2370

Using statistical parameters i.e Upper Specification limit (USL), lower specification limit (LSL) process Capability index (PCI) which is less than the standard level 1.0 and Mean, from table. 8 plotted the control charts which are shown in figure 10, figure 11 and figure 12.

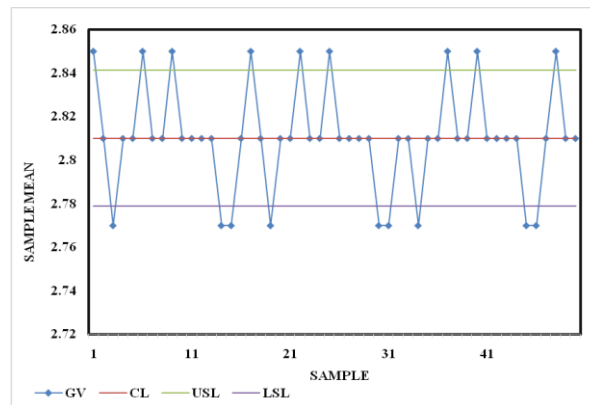


Figure 11. Fanta's control chart for gas volume

From figure 11. nine points are out of lower control limit thirty two points on central line, nine points are below upper control limit, recalculated the control limits by excluding the data points which are fallen out of control limits, which later process is in control. However, this might an indication of tool wear, poor machine maintenance, and tired operator. It does not represent a sudden change in the process, but a slight and continuous change in it. This kind of patten can be easily detected and acted on before it is too late.

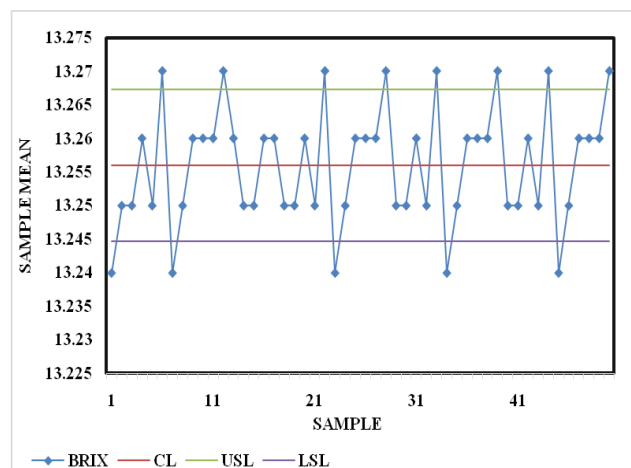


Figure 12. Fanta's control chart for brix

From figure 12. six points just near lower control limit, eight points are just near upper control limit, nineteen points above central line, eighteen points below central line. This pattern might be indicative of a sudden increase in the process variation. It is possible to have some points in this zone from time to time, but this kind of patten is not desirable in process however, process is under control.

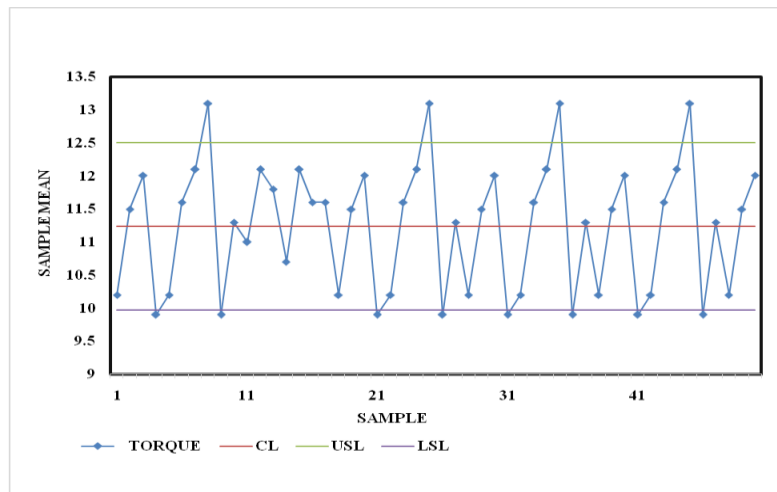


Figure 13. Fanta's control chart for torque

From figure 13. Twelve points are out of control limit, hence process is not in control, cause of data integrity either data collection to be done again for sample size and evaluate control limits for new data.

5.1 Short term /long term capability

Table 6. Assessment of Short term and Long term process capability indices

Process variability	Variability independent of time	Total variability = variability independent on time + variability dependent on time
Variability measure	$s_{short} = \sqrt{s^2}$	$s_{long} = \sqrt{\frac{1}{n-1} \sum (x_i - \bar{x})^2}$
Capability Indices	<p>Short term capability</p> $C_p = \frac{USL - LSL}{6 \cdot s_{short}}$ $C_{pk} = \min \left(\frac{\bar{x} - LSL}{3 \cdot s_{short}}; \frac{USL - \bar{x}}{3 \cdot s_{short}} \right)$	<p>Long term capability</p> $P_p = \frac{USL - LSL}{6 \cdot s_{long}}$ $P_{pk} = \min \left(\frac{\bar{x} - LSL}{3 \cdot s_{long}}; \frac{USL - \bar{x}}{3 \cdot s_{long}} \right)$

\bar{s}^2 average variance is evaluated using the variance for selected samples taken from the process. S_{short} , S_{long} S_{short} , can be used as average range or average standard deviation, however, process dispersion is independent of time and total process variability. \bar{x} , \bar{x} average values, adequately the average determined on the basis of averages from particular samples taken from the process, and the average determined on the basis of a range of values created on the basis of all samples taken obviously ($\bar{x} = \bar{x}$). C_p , C_{pk} are short-term capability indices whereas P_p , P_{pk} long-term capability indices and USL, LSL upper, lower specification limit, respectively.

Table 7. S_{short} and S_{long} capability indices of three parameters for four soft drinks

Name of Soft Drink	Capability Indices	Gas volume	Brix	Torque
Limca	$S_{\text{Short term}}$	0.0108	0.0002	0.8087
	$S_{\text{long term}}$	0.0108	0.0002	0.8087
Sprite	$S_{\text{Short term}}$	0.0001	0.0001	0.8640
	$S_{\text{long term}}$	0.0010	8.1980	0.0709
Thums up	$S_{\text{Short term}}$	0.0005	0.0001	0.6143
	$S_{\text{long term}}$	-2.9066	7.4443	0.0841
Fanta	$S_{\text{Short term}}$	0.0006	0.0001	0.9619
	$S_{\text{long term}}$	2.7190	7.4853	0.0672

(Source: Author, 2017)

From table. 7 using relevant equations of table.6 results of assessment of long-term and short-term capability indices reach to conclude that if Standard deviation S_{short} and S_{long} are equal the total process variability independent on time for the process considered in this study parameters for Limca S_{Short} is equal to S_{long} . Equality $S_{\text{short}} = S_{\text{long}}$ involves the capacity of adequate short-term and long term capability indices i.e $C_p = P_p$ and $C_{pk} = P_{pk}$. If there is an inequality $S_{\text{short}} < S_{\text{long}}$ which is observed in all cases can be interpreted as the total process variability is larger than the variability independent on time, so a position of the considered process was being changed significantly in time. from table 2 except for torque as a parameter for all four soft drinks where $S_{\text{short}} < S_{\text{long}}$ condition not satisfied. Thus inequality $S_{\text{short}} < S_{\text{long}}$ condition implies that following relations between short-term and long-term capability indices : $C_p > P_p$ and $C_{pk} > P_{pk}$. Thus the relationship between short-term and long-term process capability indices $P_p C_{pk} = C_p P_{pk}$ used as verification for the calculation correctness. Calculations done in current study satisfies this condition of correctness.[41]

Table 8. ANOVA one way testing S_{short} & S_{long} capability indices of three parameters for four soft drinks

Parameter	F_{actual}	P-Value	F_{Critical}
Gas volume	3.00	0.0087	2.96
Brix	2.92	0.0244	2.68
Torque	4.86	0.0310	3.98

(Source: Author, 2017)

From table 8 ANOVA one way results test to find any difference statistically summary reported on results of S_{short} and S_{long} capability indices of three parameters for four soft drinks(from table 2) It has been observed that there is a huge difference in their means observations as condition: $F_{\text{actual}} > F_{\text{Critical}}$ is fulfilled with p-value less 0.05.

5.2 Taguchi's loss function

As per quality guru Taguchi, monetary losses start as soon as process starts to shift away from the target value. Furthermore, taguchi mentioned that those monetary losses were experienced by society. As we move further away from target value, the monetary loss increases, following a quadratic function. Defined by the following formula $L = k (y - T)^2$ where L is monetary loss, k is a cost factor, y is actual value, T is target value. Quality loss function from figure.1 Blue line shows difference in loss level between traditional and Taguchi approach.

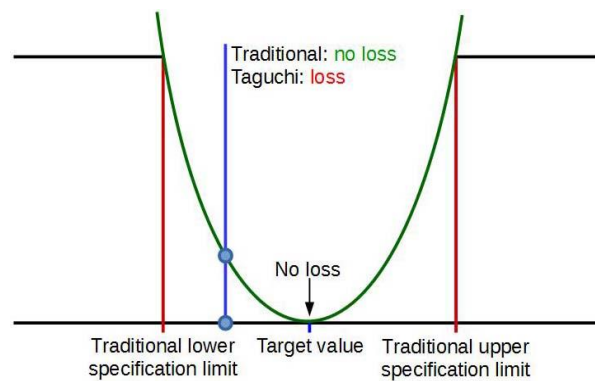


Figure 14. Taguchi loss function (Source: Ceopedia.org)

For a population of part produced at different dimensions, say, Y_1, Y_2, Y_3 , etc. average loss per product can be expressed as

$$L = K \left[(Y_1 - Y_0)^2 + (Y_2 - Y_0)^2 + \dots + (Y_n - Y_0)^2 \right] / N$$

$L = K (\text{MSD})$ [by definition of MSD]

L is always expressed as amount per part regardless of single or multiple unit of part information. If there is more than one part involved then instead of $(Y - Y_0)^2$

Table 9. Loss Function (L) for parameters of four Soft drinks

Parameters	Loss function			
	Limca	Sprite	Thumsup	Fanta
Gas volume	0.00023	0.000288	0.001008	0.001152
Brix	0.00033	0.000127	0.000154	0.000152
Torque	1.584968	1.693512	1.204072	1.885282

(Source: Author, 2017)

Using table 9 i.e loss function values, calculated the Loss function (L) as a monetary value of four soft drinks for four different cases i.e per shift, per two shifts, per three shifts and per four shifts respectively can be observed from figure. 15 assuming standard operating conditions (per shift eight hours production and capacity of production i.e filling 2880 bottles per shift, INR 2 to refill single bottle).

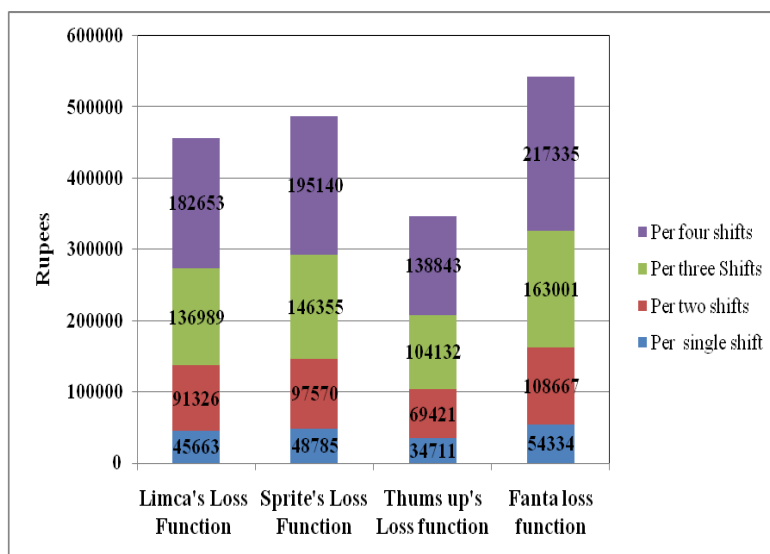


Figure 15. Projected loss function costs for four different cases

SUMMARY:

Implications with reference to processing unit management it can be acknowledged that the process meets the expectations regarding the analyzed parameters i.e gas volume, brix, torque for four soft drinks. It is worth noticing that some parameters for some soft drinks not falling within the standard limits of process capability index especially Fanta's PCI is less than 1 which is not desirable. Similarly, Thumpsup's and Fanta's : gas volume, torque processes are out of control, excluding the points which are fallen out of control and recalculated the new control limits resulted the process in control which is an exploratory view of this study. From methodological point of view the assessment of a long-term and short term process capability is a single factor analysis of variance. The aim of doing that analysis is to understand and infer the sensitivity of data, observations made are statistically acceptable for further courses of managerial, operational and analytical actions as collected data observed the normal distribution and variance equality. The causes for variation are broadly classified into seven types: equipment, indirect material, direct material, orders, people, methods and working conditions.

Implication reference to assessment of short term and long term capability an inequality $S_{\text{short}} < S_{\text{long}}$ is observed in all cases the total process variability is larger than the variability independent on time, so a position of the considered process was being changed significantly in time. Except for torque, as a parameter for all four soft drinks where $S_{\text{short}} < S_{\text{long}}$ condition not satisfied. Thus, torque process parameter for all four soft drinks has to be reconsidered to set the new targets for the processes to achieve the desired level of process capability indices. Taguchi's loss function has its own significance in any processing unit which deals with quality as a crux aiming to satisfy customers as well as producers. This study also observed that certain parameters has not been set (targeting mean) exactly in which there is a loss to producer. The loss has been projected monetarily for all selected parameters in the process, for four soft drinks for four different conditions. The loss function projected in this study helps the management in understanding/interpreting the process parameters which are not in within the specified limit which thus research study conducted an exploratory view to management of processing unit.

References:

- [1] Zhenlu Chen, Rong Pan and Lirong Cui 2017 An economic off-line quality control approach for unstable production processes, *Quality Engineering* Vol 29 no 4 pp 623-642.
- [2] Maman Abdurachman Djauhari, Revathi Sagadavan and Lee Siaw Li 2016 Monitoring multivariate process variability when sub-group size is small *Quality Engineering* Vol 28 no 4 pp 429 - 440.
- [3] Zahra Sedighi Maman W Wade Murphy Saeed Maghsoodloo Fatemah Haji Ahmadi and Fadel M Megahed 2016 A short note on the effect of sample size on the estimation error in Cp *Quality Engineering* Vol 28 no 4 pp 455- 466.
- [4] Nesma A Saleh Inez M Zwetsloot Mahmoud A Mahmoud and William H Woodall 2016 CUSUM charts with controlled conditional performance under estimated parameters *Quality Engineering* Vol 28 no 4 pp 402 – 415.
- [5] Z. Abbasi Ganji and B Sadeghpour Gildeh 2016 A class of process capability indices for asymmetric tolerances *Quality Engineering* Vol 28 no 4 pp 441- 454.
- [6] Sajid Ali and Muhammad Riaz 2014 On the generalized process capability under simple and mixture models, *Journal of Applied Statistics* Vol 41 no 4 pp 832-852
- [7] Chen S M and Tsai T J 2012 Properties of estimators of the process capability index C_{pk} *Communications in Statistics: Simulation and Computation* Vol 41 no 8 pp 1444-1462.
- [8] Hussein A Ahmed S E and Bhatti S 2012 Sequential testing of process capability indices. *Journal of Statistical Computation and Simulation*, Vol 82 no 2 pp 279–292.

- [9] Mohammad R Niavarani Rassoul Noorossana and Babak Abbasi 2012 Three New Multivariate Process Capability Indices, *Communications in Statistics - Theory and Methods* Vol 41 no 2 pp 341-356.
- [10] Daniels L Edgar B Burdick R K and Hubele N F 2004 Using Confidence Intervals to Compare Process Capability Indices *Quality Engineering*, Vol 17 no 1 pp 23-32.
- [11] Perakis Michael 2010 Estimation of differences between process capability indices for C_{pm} or C_{pk} two processes , *Journal of Statistical Computation and Simulation*, Vol 80 no 3 pp 315 — 334.
- [12] A Parchami and M Mashinchi 2010 A new generation of process capability indices, *Journal of Applied Statistics* Vol 37 no 1 pp.77- 89.
- [13] Angus Jeang 2010 Optimal process capability analysis for process design *International Journal of Production Research* Vol 48 no 4 pp 957-989.
- [14] Chien-Wei Wu and P. H. Huang 2010 Generalized Confidence Intervals for Comparing the Capability of Two Processes, *Communications in Statistics - Theory and Methods* Vol 39 no13 pp 2351- 2364.
- [15] Malin Albing and Kerstin Vännman 2009 Skewed zero-bound distributions and process capability indices for upper specifications *Journal of Applied Statistics* Vol 36 no 2 pp 205-221
- [16] K.G.Khadse and R. L. Shinde 2009 Probability-Based Process Capability Indices, *Communications in Statistics - Simulation and Computation* Vol 38 no 4 pp 884-904.
- [17] Lovelace C R and Swain J J 2009 Process capability analysis methodologies for zero-bound, non-normal process data *Quality Engineering* Vol 21 no 2 pp190-202.
- [18] Kamal Mannar and Darek Ceglarek 2009 Functional capability space and optimum process adjustments for manufacturing processes within-specs failure *IIE Transactions* Vol 42 no 2 pp 95-106.
- [19] Chen K S Huang M L and Hung Y H 2008 Process capability analysis chart with the application of C_{pm} *International Journal of Production Research* Vol 46 no 16 pp 4483- 4499.
- [20] Saxena S and Singh H P 2006 A Bayesian estimator of process capability index *Journal of Statistics & Management Systems* Vol 9 no 2 pp 269-283.
- [21] Pearn W L Shu M H and Hsu B M 2005 Testing process capability based on C_{pm} in the presence of random measurement errors *Journal of Applied Statistics* Vol 32 no 10 pp 1003-1024.
- [22] Surajit Pal 2004 Evaluation of Non normal Process Capability Indices using Generalized Lambda Distribution *Quality Engineering* Vol 17 no1 pp77- 85. DOI: 10.1081/QEN-200028709
- [23] Linda Lee Ho and Roberto C Quinino 2003 Optimum Mean Location in a Poor-Capability Process *Quality Engineering* Vol 16 no 2 pp 257-263.
- [24] Perakis M and Xekalaki E 2003 On a Process Capability Index for Asymmetric Specifications *Communications in Statistics Theory and Method* Vol 32 no 7 pp 1459-1492.
- [25] Flaig J J 2006 Process Capability Optimization *Quality Engineering* Vol 5 no 2 pp 233-242.
- [26] Nam K H Kim D K and Park D H 2002 Large-Sample Interval Estimators for Process Capability Indices *Quality Engineering* Vol 14 no 2 pp 213-221
- [27] Richard J Linn Emily Au and Fugee Tsung 2002 Process Capability Improvement for Multistage Processes *Quality Engineering* Vol 15 no 2 pp 281-292.
- [28] B Zhang and J Ni 2002 Relative Probability Index Crp : An Alternative Process Capability Index *Quality Engineering* Vol 14 no 2 pp 267-278.
- [29] K S Chen M L Huang and R K Li 2001 Process capability analysis for an entire product, *International Journal of Production Research* Vol 39 no 17 pp 4077- 4087.
- [30] Wu H H and Swain J J 2001 A Monte Carlo comparison of capability indices when processes are non-normally distributed *Qual. Reliab. Engng. Int.* Vol 17 pp 219- 231.
- [31] Niverthi M and Dey D 2000 Multivariate process capability a Bayesian perspective *Communication in Statistics Simulation and Computation* Vol 29 no 2 pp 667- 687.

- [32] Yock Wah Lai and Ek Peng Chew 2000 Gauge capability assessment for high-yield manufacturing processes with truncated distribution *Quality Engineering* Vol 13 no 2 pp 203-210.
- [33] Asokan M V and Unnithan V K G 1999 Estimation of vendor's process capability from the lots screened to meet specifications *Quality Engineering* Vol 11 no 4 pp 537-540
- [34] Wen D and Mergen A E 1999 Running a Process With Poor Capability *Quality Engineering* Vol 11 no 4 pp 505-509.
- [35] Alan Veevers 1998 Viability and capability indexes for multi response processes *Journal of Applied Statistics* Vol 25 no 4 pp 545-558.
- [36] W L Pearn 1998 New generalization of process capability index C_{pk} *Journal of Applied Statistics* Vol 25 no 6 pp 801-810.
- [37] Chen H 1997 Asymptotic Analysis of a Class of Process Capability Indices. *Statistics*, Vol 30 no 2 pp 149-162.
- [38] Levinson W A 1997 Exact Confidence Limits for Process Capabilities *Quality Engineering* Vol 9 no 3 pp 521-528.
- [39] Pearn W L and Chang C S 1997 The performance of process capability index C-s on skewed distributions. *Communications in Statistics-Simulation and Computation* Vol 26 no 4 pp 1361-1377.
- [40] <http://www.niir.org/information/content.phtml?content=184>
- [41] Czarski Andrzej 2009 Assessment of a long term and short term process capability in the approach of analysis of variance (ANOVA) *Metallurgy and foundry engineering* Vol 35 no 2 pp 111-118.