A Study on Managing Processes By Statistical Process Control

*** Soumitra Karan**

INTRODUCTION

Relentless pressure is mounting on the strategists to seek solutions to ward-off stiff competition, continual quality improvement and lowering cost of products/services in global economic turbulence. Need of the hour is to find out an efficient system that serves the purpose of quality improvement with cost-effectiveness at every stage of the business process to both internal and external customer to outperform competition. This invokes practice of SPC, a barometer of quality commitment where process performance and capability are the determining factors to satisfy customer specifications. The emerged marketing philosophy of outside in approach is the key where customers set decisive target and the firm has to meet it. This signifies implementation of QS-9000.

Therefore, SPC is a proactive dynamic system by which a market driven firm strategically controls its processes and produces outputs that converge to satisfy ever changing customer needs consistently.

RESEARCH OBJECTIVE

Knowledge equity must be translated into benefits through foundation of actions involved in processes where performance & capability are evaluated by the extent of overlap between organizational capability and customer need. People become focused and acquire diagnostic skill to pursue continual improvement of processes to offer best quality products & services proactively. The research objective is to shed light on how SPC works as (1) an efficient system of overall understanding of process behaviour & process change (2) and a continual quality improvement management system. (3) Performance measurement tool in terms of customer satisfaction. (4) Cost effective tool. (5)A ladder of organizational journey that raises customer's satisfaction to delight. Therefore, the underpinning philosophy of this article is to superimpose the voice of customer with voice of process within the SPC framework.

RESEARCH METHODOLOGY

To have more panache first, basic understanding of process control including a model with feed-back mechanism, concept of variation, contribution of local actions and actions on system, objectives of control and process capability has been discussed, then a strategic control formulation has been derived on situational analysis. Short term capability indices guide the setting of engineering parameters and long term capability indices allow the process to weed out as much assignable and chance cause variations to satisfy customer specifications over long term. Goal of SPC is a continual stage wise process improvement program accomplished by using of control charts. In this article, we have taken process average - range ($\overline{X}$ - R) chart with appropriate statistical formulas to examine analytically the nature of variations and then we have discussed and recommended plausible control techniques. It has been further extended for fine tuning applying statistical Z variates where uses of various process indices especially process performance and process capability indices acknowledge process health and evaluate improvement level seeking possibilities of shrinking control limits and specification limits towards central target. In addition, process centering technique is also discussed to accommodate as much off data inside the control limits. We have underpinned the importance of journey towards central target specification i.e. matching / superimposing customer voice with process voice. Finally, a plausible SPC implementation model has been recommended for easy practice in any process industry as guidelines.

BASIC UNDERSTANDING OF PROCESS CONTROL (PC)

In the study of SPC, basic statistical methods are used. The aim is:

(1) To have controlled output.

(2) To improve quality, increase productivity and reduce cost.

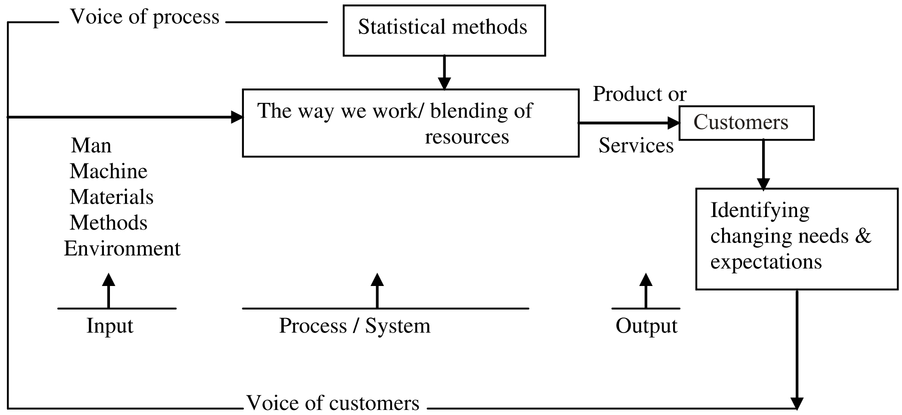
(3) To provide "Rule of Thumb" without hampering increase of knowledge of statistical methods and theory.

(4) To assume that measurement system is under control and has minor impact on total data variation.

The strategy is " Do the right thing first" which zeroes in on plugging- off resource drain to impart more value to products by implementation of SPS system.

* *Dy. Manager,* Technical Sales, Birla Tyres, HO, Shivam Chambers, Kolkata - 700019.
E-mail : soumitrakaran@yahoo.co.in

Process Control System Model with Feedback Mechanism



The above illustration is a comprehensive process control model with feedback mechanism of any process industry. The model aligns the voice of customer (feedback) with the voice of process. Marketing starts with identifying changing needs and expectations of company's target audience that organizes inputs / resources i.e. man, machine, materials, methods to be worked or blended in co-ordinated and sequential processes / system to produce outputs(products / services) of acceptable quality to its valued customer.

Marketing myopic company screens out off- specification output by 100% inspection as quality control system which highlights product behaviour overtly, but SPC focuses deep insight on the controlling factors of process health in an organizational environment responsible for ailing output.

The effectiveness of process performance depends on the communication between manufacturer and its target audience, process design & implementation. Then situational analysis either aims to maintain that achieved excellence level or improve further. Output quality is the index of process performance which is the function of internal variability. Process parameters e.g. temperature, climate, cycle time, feed rate, absenteeism, tardiness, turnover, nos. of interruption, frequent change of process parameters/ setting disturbance etc. are the major issues of managerial functions and need target values for continuous / focus improvement (Kaizen schemes) timely.

Measures must be economical for the parameters which are far from target values & demand operator training, changing incoming materials, improvement of working environment or basic elements of process equipments needing rehabilitation & process design as a whole, communication system, finding-out efficient methods etc.

Only inspection followed by actions on output is a poor substitute for effective process management but professes interim measures for unstable/ introductory, uncoordinated or incapable processes. Sometimes actions may be least economical when it is restricted to detecting and correcting out -of specification products on exigencies without addressing underlying process problem. If current output does not confirm specification, it is necessary to sort out all products and scrap or downgrade/ rework as per company's established disposition standard until and unless necessary corrective measures on processes are taken , tested , verified or production specification has been changed.

CONCEPT OF VARIATION

Variation in process is a natural phenomena and the cornerstone of SPC study. It deals with data distribution characterized by:

(1) Location or central tendency.

(2) Dispersion or spread from smallest to largest.

(3) Shape or pattern (symmetrical or skewed)

Variation results from (a) chance causes (b) assignable causes (c) combination of both. In a state of statistical control, there exists only chance cause variations where resultant output is stable, predictable and acceptable. Assignable causes refer to any factor not always acting on process but its presence changes overall distribution. It is possible to assign the causes and eradicate them in order to bring back the process under control to get output of desired specifications. It is noteworthy that not all assignable causes are detrimental; rather some are beneficial to customer requirements . It is to identify & include them permanently in process parameter roster provided that the mature process is protected from other detrimental chance causes.

LOCAL ACTION AND ACTION ON SYSTEM

Action on processes are of two types : (1) local actions are short lived and taken on assignable causes that contribute only 15% of process problems typically addressed and corrected by local persons close to process. (2) action on system is a long term management planning to minimize variations due to chance causes. This accounts for 85% of the process problems. Care must be taken for addressing, isolating and categorizing process problems to avoid wrong selection of actions which can only delay rectification process, contributing to wastage of resources.

PROCESS CONTROL AND PROCESS CAPABILITY

As discussed, the objective of process control is to provide effective and economic decisions about selection of actions on variations. This balances the risks of consequences of over and under control. World class manufacturers use statistical signals to alert when assignable causes appear in the production process and then decide whether it should be eradicated or retained permanently for customer benefits.

Process capability is determined by variations resulted from chance causes. The performance is best evaluated by minimum dispersion of variations in a state of statistical control but not defines output specifications in terms of process location and / or dispersion. In contrast, internal / external customers are concerned with overall output characteristics and how they are related to their requirements i.e. specifications. Balancing these two parameters, first it is to locate the process on target value and then examine whether the dispersion limits are acceptable or not.

Strategic control formulation Control

Customer requirement	In control	Out of control
Acceptable	Case – 1	Case – 3
Not acceptable	Case –2	Case – 4

Case -1 : To be acceptable, the process must be in statistical control and inherent variations must be within designated tolerance limits.

Case 2 : The process is in statistical control but excessive chance cause variations render output unacceptable. It requires management actions to reduce extent of chance cause variations.

Case 3 : The process meets customer requirements but not in control. This indicates assignable causes to be identified and acted upon.

Case 4 : Both chance and assignable causes of variation are present in process causing not in statistical control and output unacceptable.

SHORT TERM AND LONG TERM CAPABILITY INDICES

Short term capability indices validate initial parts produced from a system for customer usage and a new or modified process performs actually within the engineering set parameters. Long term capability indices dealing with data collected over long periods cover all sources of variations, many of which may not be covered in short-term study. The focus is on fulfilling customer requirements over long term i.e. to improve process performance.

In SPC, no single index is universally applicable to all processes e.g. Cp & Cp_k both are used and sometimes coupled with graphical techniques for better understanding of the relationship between estimated distribution and specification. This accounts comparing and aligning voice of process with voice of customer. The excellence of process capability lays on mutual agreement on fixing specification.

STAGES OF CONTINUAL PROCESS IMPROVEMENT

It is a three stage cyclic process and each process seeking improvement is to be located somewhere in the cycle.

(1) Process analysis by : (a) secondary data :
- review of process history.
- Failure Mode Effect Analysis (FMEA)

(b) primary data :
- group meeting
- control charts

The purpose is to differentiate chance and assignable causes.

(2) Maintain the process : As processes changes over time, the process performance needs to be monitored and measured to prevent undesirable changes. If desirable changes occur that is to be institutionalized, otherwise present status should be maintained.

(3) Improve the process: It represents higher level actions and uses more advanced statistical measures or advanced control charts for better quality finesse. The procedure is to introduce small changes into the process and measure the effects for better understanding that further reduces chance causes.

CONTROL CHARTS

These are effective diagnostic SPC tools for process scanning and monitoring associated with three basic phases.

(1) Data collection : Data are measured values of dimensions of any process parameter.

(2) Control : Trial control limits are drawn using statistical formulas. These are the guides for analysis and actions and not for specification limits but things depends on natural variability of process and sampling plan. Collected data are then compared with trial control limits to see whether the variation is stable , random and originating from chance causes only.

If assignable causes are evidenced, then local actions are taken. Further data are collected and control limits are recalculated to re-examine presence of any additional assignable cause.

(3) Analysis and improvement : If the process is in statistical control , control charts continue to monitor and process capability is calculated. If excessive chance causes claim inconsistent and unsatisfactory output, management actions are taken. This reduction of chance cause variations results in shrinkage of control limits towards the center which is the prime objective of SPC.

CONTROL CHARTS FOR VARIABLES:-

These charts explain both data to data variability and their locations (process average) in pairs. Among varieties of control charts, the commonly used is $\overline{X}$ - R charts (Average range).

PREPARATION FOR USE OF CONTROL CHARTS :

- Establish an environment conducive to management actions
- Define the process
- Determine characteristics to be measured

WHILE PREPARING, FOLLOWING CONSIDERATIONS ARE TO BE KEPT IN MIND :-

⇛ Customer needs
⇛ Current potential characteristics
⇛ Correlation between characteristics
⇛ Define measurement system
⇛ Minimize unnecessary variation

GATHERING DATA:

(1) Select sample size, frequency and nos. of subgroups:

Variation within subgroup would be small and primarily of chance causes. On the other hand, unusual variations between subgroups would reflect changes/ shift in processes and may be of assignable causes. Sample size remains constant for all sub-groups.

In determining sub-group frequency, these are collected often enough in time that reflect potential opportunities for change to identify cause/s e.g. work shift difference, relief operator, warm-up trend, material lots etc. Sub- group frequency for ongoing monitoring could be twice per shift, hourly or some other feasible rate.

Generally 25 or more sub-groups containing 100 or more individual readings give a good test for stability and estimate.

(2) Set up control chart & record raw data

(3) Calculate average ($\overline{X}$) & range ($\overline{R}$) for each sub group: Collectively these represent process average and its variability respectively.

(4) Select appropriate scale

(5) Plot averages and ranges

(6) Calculate control limits :

(a) Calculate : $\overline{\overline{X}}$ (process average) & $\overline{R}$ (average range)

They signify the extent by which subgroup averages and ranges would vary if only chance causes are present.

(b) Control limits for averages : $UCL_{\overline{x}} = \overline{\overline{X}} + A_2\overline{R}$ (Upper limit)

$LCL_{\overline{x}} = \overline{\overline{X}} - A_2\overline{R}$ (Lower limit)

Control limits for ranges : $UCL_{\overline{R}} = D_4 R$, $LCL_R = D_3\overline{R}$

Where D_4, D_3 & A_2 are constants varying in sample size.

Sample size below 07 , $LCL_{\overline{R}}$ is – ve and considered no control limit.

(C) Draw $\overline{R}$, $\overline{\overline{X}}$, $UCL_{\overline{R}}$, $LCL_{\overline{R}}$, $UCL_{\overline{x}}$ & $LCL_{\overline{x}}$

(7) Interpret for process control :

$\overline{X}$ & R chart are useful for comparison of patterns between two charts and provides whether any assignable cause affects the process.

Analysis of range chart: Points beyond control limits evidence out of control situation at that point due to assignable cause/s.

Obvious non-random patterns: This signifies presence of assignable causes. Sometimes, there may be an illusion of chance causes. Therefore, over interpretation must be avoided. Examples of data non-randomness are obvious- trends, cycles, overall data dispersion within control limits or even relationships among the values within sub-group e.g. first reading might be always the highest.

Recalculation of control limits: while reassessing process capability, control limits are recalculated excluding the out of control points or periods for which process causes are identified , removed or institutionalized. Exclude all sub-groups affected by assignable causes, recalculate and plot $\overline{\overline{X}}_{new}$, $\overline{R}$ and control limits. For better understanding, old control charts are kept for future reference.

Extend control limits for ongoing control:

- Ensure historical data are consistent with in control limits .
- If required, adjust the process to target i.e. process centering.
- Use these limits for ongoing process monitoring..

FINAL CONCEPTS ON CONTROL FOR FURTHER CONSIDERATION

An ideal state of control is never attainable but efforts are directed to achieve the optimum level.

Interpretations for process capability :

The assumptions are :

❖ The process is in statistical control and individual measurement follows normal distribution.
❖ Engineering and other process specifications represent customer needs.
❖ The target is in the center of specification width.
❖ Measurement variation is relatively small.

SPC provides only approximate results because :-

⇛ Existence of sampling variation
⇛ No process is ever fully in statistical control
⇛ No actual output exactly follows normal distribution.

CALCULATION OF PROCESS STANDARD DEVIATION :

$\delta^{\wedge} = \overline{R} / d_2$, where d_2 is a constant depends on sample size.

Process capability is described in terms of the distance of process average from the specification limits in standard deviation units, Z.

- For unilateral tolerance : $Z = \dfrac{USL - \overline{\overline{X}}}{\overline{R} / d_2}$ or $Z = \dfrac{\overline{\overline{X}} - LSL}{\overline{R} / d_2}$

Whichever is appropriate , where $\overline{X}$ = measured process average and $\delta^{\wedge}_{\overline{R}/d2}$ = estimated Std. Deviation.

- For bilateral tolerance, $Z_{USL} = \dfrac{USL - \overline{\overline{X}}}{\delta^{\wedge}_{\overline{R}/d2}}$ & $Z_{LSL} = \dfrac{\overline{\overline{X}} - LSL}{\delta^{\wedge}_{\overline{R}/d2}}$

$Z_{Min.}$ = Min. Z_{USL} or Z_{LSL} , where USL& LSL are upper and lower specification limits respectively. Negative value of Z implies the process average is out of specification.

IMPORTANCE OF Z VALUES

Assuming normal distribution Z values from normal distribution table estimate the proportion of out of specification output.

e.g. for unilateral tolerance : $Z = 1.54$, $Pz = 0.0618 \cong 6.2\,\%$

For bilateral tolerance : $Pz_{USL} + Pz_{LSL} = 0.0797 \cong 8.0\,\%$.

Where, say : $\overline{\overline{X}} = 20.47$, USL = 20.70, LSL = 20.30, $\delta^{\wedge} = 0.11$ & Z Min. = 1.54,Capacity index C_{Pk} = Z Min. / 3 = 0.513 (Min. of CPU or CPL).

For comparative purposes other indices are :

$$C_P = \frac{USL - LSL}{6\,\hat{\delta}_{\bar{R}/d2}} = 0.606$$

$$Pp = \frac{USL - LSL}{6\,\hat{\delta}s} = 0.385, \text{ where } \hat{\delta}s = \sqrt{\frac{\sum_{i=1}^{n}(\overbrace{Xi}^{\text{individual reading}} - \overbrace{20.47}^{\bar{\bar{X}}})^2}{\underbrace{9}_{n-1}}} = 0.173$$

where n =10 [taking only 10 individual reading]

$$CPU = \frac{USL - \bar{\bar{X}}}{3\,\hat{\delta}_{\bar{R}/d2}} = 0.697, \quad CPL = \frac{\bar{\bar{X}} - LSL}{3\,\hat{\delta}_{\bar{R}/d2}} = 0.515$$

$$Ppk = \frac{(USL - \bar{\bar{X}})/\hat{\delta}s}{3} = 0.443$$

Cpk = Min. of CPU or CPL = 0.515

Capability ratios are : $C_R = 1/Cp = 1.65$ & $P_R = 1/Pp = 2.60$

Process adjustment towards the center of specification is done where proportion of data falling beyond specification limits without change in s, e.g. $\bar{\bar{X}}_{new} = 20.50$ (centred) , then $Z_{USL} = Z_{LSL} = 1.82$.The proportion of off-spec. output would be $Pz_{USL} + Pz_{LSL} = 0.0344 + 0.0344 = 0.0688 \cong 7\,\%$.

New Capacity index would be = Z Min./3 = 0.607.

A process having Z Min. = 3 would have a $Cp_k = 1.0$, if Z Min. = 4, then $Cp_k = 1.33$.

Only process centering not always satisfies to accommodate more data which are out of control limits. If it fails, then it is necessary to look into reduction of chance cause (i.e. lowering δ).

EVALUATION OF PROCESS CAPABILITY

Two stop gaps are available as short-term measures (1) adding cost and tolerating waste by sorting output and scrap or rework or downgrade as necessary. (2) Matching specification with current process performance. Both are dangerous as no improvement results in either process or customer satisfaction.

Discarding the above two, SPC evaluates process improvement by comparing process capability before and after the actions on chance causes through analysis of control charts.

UNDERSTANDING OF PROCESS CAPABILITY AND PROCESS PERFORMANCE INDICES

If center of distribution is not properly located, then the process may produce a fraction of output that deviates from desired target value. Likewise, if dispersion is too large regardless of center of location, the same may happen. Therefore, it is essential to evaluate process variation in terms of both Cp & Pp with respect to specification.

For basic understanding of process indices and centering relative to specification, some definitions are:

• **Inherent process variation: -** The extent of process variation resulted from chance causes is estimated from control charts by $\bar{R}/d_2$.

• **Total process variation :-** Variation is from both chance and assignable causes estimated by sample standard deviation given by :-

$$S = \sqrt{\frac{\sum_{i=1}^{n}(Xi - \bar{X})}{n-1}} = \hat{\delta}s \text{ Where } X_i = \text{individual data}, \ \bar{X} = \text{average},$$

n = nos. of data

• **Process capability :** The 6δ range of process's inherent variation where δ is estimated by $\bar{R}/d_2$.

• **Process performance:** The 6δ range of process's total variation where δ is estimated by s, sample std. deviation.

• **Cp :** This is capability index defined as tolerance specification width divided by process capability and expressed as (USL - LSL) / $6\hat{\delta}_{\bar{R}/d2}$.

• **Pp :** This performance index is defined as tolerance specification width divided by process performance irrespective of process centering and expressed as

$(USL - LSL) / 6\hat{\delta}s$.

• **Cp_k :** This is the capability index of process centering and defined by minimum of CPU or CPL. It measures the distance between process mean and the closest specification limit to the half of total dispersion.

• **Pp_k :** This is the performance index for process centering and defined as minimum of $(USL - \bar{\bar{X}}) / 3\hat{\delta}s$ or $(\bar{\bar{X}} - LSL) / 3\hat{\delta}s$ used only to compare with CP & Cp_k for measuring and prioritizing improvement over time.

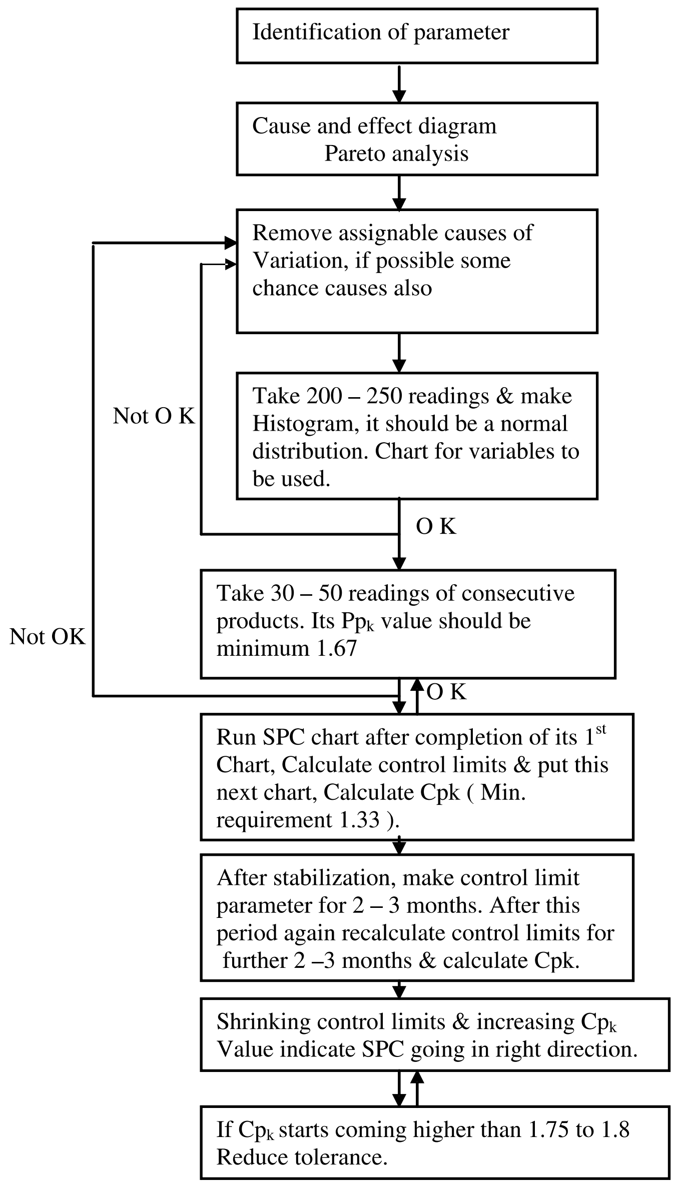
• **Cp_k** is useful for determining the extent of meeting customer requirement where as Pp_k is used for continual improvement of process performance within the tolerance limits of specification regardless of their locations. Pp_k examines whether process variations are obeying engineering specification or not.

• Measurement and plotting of process variation ($\bar{R}/d_2$) vs. total process variation ($\hat{\delta}s$) determine the gap between process capability and process performance and also tracks improvement and determine the extent of out of control and type of actions (local or management or both) required. In ideal case $\hat{\delta}s$ tends to $\bar{R}/d_2$, Pp_k tends to Cp_k.

MATCHING VOICE OF CUSTOMER WITH VOICE OF PROCESS

Customers become happy if their product specifications are met. The utmost responsibility and accountability of

Implementation model of SPC



suppliers is to satisfy them consistently. The challenge is to have a process system of minimum variations where (1) process specification is superimposed with customers' specification (2) concentrate the variations around the central specification by reducing dispersions . Both the cases offer leverages to market oriented companies to create significant values to the customers. In real life situations, this little happens but companies should pursue to get maximum overlap between voice of customer and voice of process as basically these two are the two sides of the same coin.

CONCLUSION

SPC study highlights in-depth understanding of process behaviour and provides analytical eyes by which organization hones its skill to reduce process variations and enhances performance to meet customer voice through cost-effectiveness. It is noteworthy that SPC is not a panacea but assists management to take appropriate decisions for actions economically by analysis of representative samples at each stage of production process. It builds a unique problem solving production quality matrix, where economies of scale is emboldened by quality commitment. Therefore, it is a profit aid by which both suppliers and customers enjoy win-win benefits.

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