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A brief Guide to Statistical Quality Control SQC

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Abstract : **:** Statistical Quality Control (SQC) is a method used to determine whether variations in product quality arise from random or assignable causes. Rather than inspecting every single item produced, SQC involves sampling and applying significance tests to assess quality. It plays a crucial role in maintaining consistent product quality and minimizing defects.

Statistical quality control (SQC) is the application of statistical methods to monitor and manage the quality of a production process. Its primary goal is to ensure that the process operates efficiently, resulting in more specification-conforming products and minimizing waste or scrap.

I. Introduction

II. Here are some key points about SQC:

III. Definition: SQC involves using statistical techniques to validate the quality of goods and services. It encompasses both visualizing and interpreting data to anticipate outcomes. The ultimate aim is to meet customer requirements in terms of price, safety, availability, reliability, and usability while maintaining the most economical approach2.

IV. Components:

V. **Statistics:** The collaborative study of data accumulation, analysis, interpretation, and presentation.

VI. **Quality:** The degree of perfection that satisfies customer requirements.

VII. **Control:** Measuring and inspecting a phenomenon for a product or service, determining when and how much to inspect, and implementing corrective actions2.

Discussion.

Methods and Techniques:

SQC employs various statistical tools based on probability theory. These tools help establish quality standards and distinguish between defective and non-defective items.

It can be part of the production process or a last-minute quality control check2.

Comparison with Statistical Process Control (SPC):

SPC focuses on controlling process inputs (independent variables), while SQC monitors process outputs (dependent variables)3.

Both SPC and SQC contribute to efficient production and improved product quality.

Statistical Quality Control

Variation in quality of manufactured products is classified in to two causes.

1. **Chance causes 2. Assignable causes.**

Chance causes: Some stable pattern of variation or a constant cause system is inherent in any particular scheme in nature. The pattern results from any causes that behave in a random manner. The variation due to these causes is beyond the control of human and can not be prevented or estimated under any circumstances. The range of such variation is known as natural tolerance of variation.

Assignable causes: This type of variation attributed to non-Radom or s called assignable causes and is termed as preventive variation. The assignable causes may be identified and eliminated and are to be discovered.

The main purpose of statistical quality control is to devise statistical techniques which help us in separating the assignable causes for the chance causes, thus enabling us to take immediate remedial action whenever assignable causes are present. The production process is said to be in state of statistical control if, it is governed by chance causes, in the absence of assignable causes of variation.

Advantages of Process When It Is In Good Statistical Control:

1.The act of getting a process in statistical control involves the identification and elimination of assignable causes of variation and possibly the inclusion of good ones a. This helps in the detection and correction of many production troubles b. brings about a substantial improvement in the product quantity and reduction of spoilage and rework.

2.It tells us when to leave a process alone and when to take action to correct troubles, thus preventing frequent and un-warranted adjustments.

3.If a process in control is not good enough, we shall have to make more or less a radical (fundamental)change in the process-Just meddling (tempering) with it won't help.

4. A process is control is predictable- we know what is going to do and thus we can more safely guarantee the product. In the presence of good SQC by the supplier, the previous lot supply evidence on the present lots, which is not usually the case in the process is not the case other wise.

5. If the testing is destructive (example explosives , crackers) a process in control gives confidence in the quality of untested product which is not the case otherwise.

6. It provides better quality assurance at lower inspection cost

7. Quality control finds its application not only in the sphere of production, but also in other areas like packing , scrap ad spoilage, recoveries, advertising etc.,

8. The very presence of a quality control scheme in a plat improves and alerts the personnel. Such a scheme is likely to bread 'quality consciousness throughout the organization which is of immense long – run value.

9. *S.Q.C reduces waste of time and material to the absolute minimum by giving an early* warning about the occurrence of defects, Saving in terms of the factors stated above means less cost of production and hence may ultimately lead to more profits.

Process Control: The main object of any production process is to control the quality of the manufacture product so that it confirms to specifications. In other words, we want to ensure that the proportion of defective items in the manufactured product is not too large. This is called 'process control' and is achieved through the technique of control charts.

Control Charts: The epoch-making discovery and development of control charts were made by young physicist Dr.Walter A. Shewart of Bell Telephone Laboratories in 1924 and the folowing years. Shewhart's control charts provides powerful tool of discovering and correcting the assignable causes of variation outside the 'stable pattern' of chance causes.

3σ control Limits : 3σ limits are proposed by Dr.Shewart for this control charts from various considerations, the main bring probabilistic considerations. Let θ be the population parameter under considerations. Let t = t($x_1, x_2, \ldots\ldots, x_n$) of sample observations $x_1, x_2, \ldots\ldots, x_n$ be the corresponding statistic. Let

$E(t) = \mu_t$ and $Var(t) = \boldsymbol{\sigma^2}$

If 't' is normally distributed , then

$P\{ \mathbf{I}t - E(t) \mathbf{I} < 3\boldsymbol{\sigma} \} = 0.9973$

$P\{\mu_t - 3\sigma < t < \mu_t + 3\sigma\} = 0.9973$

In the words the probabability that a random value of 't' goes out side the limits $\mu_t \pm 3\sigma = 0.0027$, which is very small. Hence if t is normally distributed the limits of variation should be between $\mu_t + 3\sigma$ **and** $\mu_t - 3\sigma$ **.** Which are termed as respectively upper control limit (UCL) and lower control Limit (LCL). If , for the sample of the observed t_i lies between upper and lower control limits. It is only when any observed t_i falls outside the control limits it is considered to be danger signal indicating that some assignable causes are present, we have to eliminate them.

Remark:- If the assumption regarding normality of the statistic t does not hold, then the above assumption does not remain strictly valid.

1.Hence even for non-normal population 3σ limits are almost universally used.

2. if none of the sample points falls falls outside the control limits and if there is no evidence of non-random variation with in the limits, it don't not imply the absence of assignable causes altogether.

3. It has been emphasized strongly by Dr.Shewart that a production process should not be adjusted in statistical control unless the random variation pattern persists for quite some time and for a sizable volume out put.

Tools For S.Q.C

The following four, separate but related techniques, are the most important statistical tools for data analysis in quality control of manufactured products.

1.Shewart's control charts for variables ie., for characteristics which can be measured quantitatively. Example; diameter of a screw, tensile strength of a steel pipe, specific resistance of wire, life of an electric bulb, etc., .Such variables of continuous type and regarded to follow normal probability l aw. For quality control of such data, two types of control charts are used and technically these charts are known as.

a.Charts for $\bar{x}$ (mean) and R chart (Range)

b. Charts for $\bar{x}$ (mean) and R chart (Range) and σ (standard Deviation)

2. **Shewart's control charts for Fraction Defective or p-chart:**

This chart is used if we are dealing with attributes in which case the quality characteristics of product are not amenable to measurement but can be identified by their absence , presence form the product or by classifying the product as defective or non defective.

Example: Test Tube, Refil, pen etc.,

3.Shewart's control charts for"number of defectives" per unit or c-chart:

This is usually used with advantage when the characteristic relating to quality of the product discrete variable. Example the number of defects in an aircraft wing, the number of surface defects on a roll of paper.

4. The portion of the sampling theory which deals with quality protection given by any specified sampling acceptance procedure.

Control Charts Versus Capacity

The process is in control if there is no special causes of operating. For example, assume that the process produces tablet whose weight vary randomly between 499 mg to 503 mg, with no apparent pattern to the fluctuation. This process is in the state of control. However, if the design specification calls for weight between 501 mg to 505 mg, very little of the output that meets a given specification called capacity of process.

Process control must be done continuously:

There are three basic phases to the use of control charts, First data collected, second, these data are plotted to determine whether the process is in control. Third, once the process is brought in to control, its capacity may be assumed. Process must be continuously monitored to see whether the process is under control or not.

Similarity Between control charts and Hypothesis:

Control charts function in many ways like hypothesis test. The null Hypothesis is that the process is under control. The control charts presents data that provide evidence about the truth of this hypothesis. If the evidence against the null hypothesis is sufficiently strong, the process declared out of control.

Dimensions Of Quality

Quality is a multi-dimensional. It is not a single characteristic. Total product basically means that all characteristics of quality must be individually high on the quality criteria. Some of these characteristics are defined by Ruch, Fearson and Wieters as follows.

1. **Functionality:** it refers to performance of the product as designed and produced. It can be measured on a yes- no basis such as whether a radio works or not it can be measured in continuous basis such as how many miles a car goes on a gallon of gasoline.

2..Reliability:: it refers to performance from different angles such as.:

- Howe long will the product function every time it is used or does not fail to function occasionally (functional reliability)
- Does the product function every time it is used or does not fail to function occasionally (functional reliability)
- If the product has many components, such as car and each component has its own probability of failure (system reliability)
- Consistency in the level of quality of each successive unit produced by the given process. (Process reliability)

2. **Durability:** Durability involves not only the time prod in which the product is expected to function, but also the conditions under which it must operate, such as heat, cold, dust, vibrations so on.

3. **Aesthetic Characteristics:** A quality product should be shabby looking, even it functions well. Aesthetic refers to smoothness of surface, symmetry and absence and dents or scratches.

4. **Safety:** A high quality product should not perform its function with out unnecessarily endangering the safety of the user. Eg., under normal use electric appliances should not produce any electrical shock.

Dr.Deming's Philosophy, Expressed In 14 Principles Of Quality Improvement

1.Create constancy of purpose towards improvement of product and service with the aim to become competitive and to stay in business o provide jobs. Such objectives should be achieve such objectives.

2. Adopt a new philosophy, this philosophy should become continuous quality improvement philosophy where the quality is built in the product. We no longer accept the commonly accepted levels of delays, mistakes and defective workmanship.

3. Cease dependence on inspection to achieve quality. Prevent defects, rather than inspect defectives.

4. End the practice of awarding business on the basis of price tag. This means you should not buy from supplier on the basis of low price alone. Price should be combined with the quality of the product.

5. Improve constantly and forever the system of production and service to improve quality and productivity, thus constantly decrease costs.

6. Institute modern methods of training on the jobs.

7. Institute leader ship. Supervisors should help workers in every fact of operation and be attentive to the needs of workers and provide them with necessary tolls and instruments.

8. Drive out fear, so that every one may work efficiently for the company. People perform their best when they feel secure in their work environment.

9. Break down barriers between departments. People in various departments such as Research, design, production and marketing must work as a team.

10. Eliminate slogans, exhortations arbitrary numerical goals and targets for the workforce to achieve new levels of productivity and quality. Simply asking the workers to improve tdheir work is not enough. The whole system must be refined so that the workers understand how to improve quality.

11. Estimate work standards that prescribe numerical quotas .Quotas are purely quantitative .Quality can be sacrificed when workers are expected to meet the quota and they attempt to do so at any work.

12. Remove barriers that rob employees of their pride workman ship. People must be dtreated as human beings rather than simply machines.
13. Institute a vigorous programme of education and self-improvement. Continuous improvements require continuous learning.
14. Put everybody in the company to take all necessary steps to accomplish the transformation from the old system of thinking to the new work ethic as desired in the guidelines. Develop a plan and organizational structure that will facilitate and enhance this information.

S.Q.C can be categorized the two groups

1. One group primarily deals with quality of the incoming material known as "Accepting sampling"
2. The second category of SQC involves control of quality product during its production process.

Acceptance Sampling

Acceptance sampling is a statistical method which enables us to make a decision of either acceptance or rejecting a shipment of items in lots, based o the inspection of a sample items from the lot. In most situations 1000% inspection of all items is neither desirable nor economically feasible. However, in most cases, a random sample of established size from a given lot of items is adequate for the purpose of inspection in providing the decision maker with a criteria to whether to accept the lot or to reject it, based on the results obtained from such a sample.

Advantages of Acceptance sampling:

1.It is more economical as against 1005 inspection
2.It is more accurate than 100% inspection, since it allows less opportunity for inspection fatigue, which can be responsible for mistakes.
3. Less product damage occur since it requires less handling of product.
4. Rejecting the entire lot on the basis of sample testing can motivate the suppliers of the product to improve their quality control standards and procedures.
5. it is the only approach in situations where quality is tested by destroying the item example: if we want to test the extent of damage a car incurs on crash of 30 miles per hour we can not subject every car to test.

Sampling Plans

When a sample taken for a lot inspected, the inspected items are classified as either good or defective.. A defective item is one which does not meet the specified requirement. A good lot is open which has low proportion of defective items in it.

1.Single Sapling Plan: It means decision to accept or reject the lot is based on the inspection of single sample . It involves three elements, namely the lot size(N), the sample size(n) and acceptance number (c). The decision rule is that the sample size(n) taken from lot of size (N) and if the sample contains more than © defectives, the lot is rejected, other wise lot accepted.

Let N= 1000, n=100, c=3

If the sample size is 100 units from a lot of 1000 units containing more than 3defectives n it, then the entire lot is rejected, other wise the lot is accepted.

2.Double sampling plan: it means that the inspection of the first sample leads t a decision to accept, reject or take a second sample. The inspection of the second sample , when required would lead to a decision to either accept or reject the lot

The double sampling plan gives the inspector two sample sizes (n_1, n_2) and two acceptance numbers (c_1 and c_2). The second acceptance number c_2 applies to both samples combined.

$N=1000$, $n_1=100$, $n_2=200$, $c_1=3$, $c_2=9$, $n_1+n_2=300$

The procedure will be as follows:

1.Inspect the first sample of 100 units from 1000 units.
2.If the sample contains 3 or fewer defective units, accept the lot. Then there is no need to take the 2nd sample.
3. If the 1st sample contains more than 3 but not more than 9 defectives then take a second sample of 200 units from the lot.(If the 1st sample contains more than 9 defective, then reject the entire lot and there is no need to take second sample.)

4. Inspect the 2nd sample items 200. If the two samples combined (100+200=300) contain nine of fewer defectives, then accept the lot, other wise reject the entire lot.

2. **Multiple or sequential sampling:** This plan gives the inspector a series of samples sizes found for each of these samples, an acceptance number and rejection number. The process is similar to double sampling plan and acceptance and rejection numbers applied to the combined samples.

STEPS FOR $\bar{x}$ **AND R-CHARS TO DRAW VALIED CONCLUSIONS**

1. Equipment and Gauges: Actually the work of control charts starts with first measurements. Any method of measurement has it s own inherent variability. errors inn measurement can enter into the data by:

i) The uses of faulty instruments.

ii) Lack of clear cut definition of quality characteristics and the method of taking measurements.

iii) Lack of experience in the handling for use of instruments etc.,

since the conclusions drawn from control chart are broadly based on the variability in the measurements as well as the variability in the quality being measured, it is important that the mistakes in reading measurement instruments or errors in recording data should be minimized so as to draw conclusions from control charts.

2. Selection of samples or sub groups: In order to make the control chart analysis effective, it is essential to pay due regard to the rational selection of the samples or sub groups. The choice of the sample size 'n' and the frequency of sampling ie., the time between the selection of two groups, depend upon the process and no hard and fast rules can be laid down in this purpose. Usually 'n' is taken to be 4 or 5. Initially, more frequent samples will be required (15 to 30 minutes) and once a state of control is maintained the frequency may be relaxed. Normally 25 samples of size 4 each or 20 samples of size 5 each under control will give good estimate to the process and dispersion.

Remark: While collecting data it may be necessary to go exactly at the specified time; in fact this should not be practiced. This is to avoid i) the operative being careful at the time of sampling ii) any predictions of the process to coincide with sampling.

3. Calculation of and R for each sub-group:

Let xij, j=1,2, …….n be the measurements on the' i' th sample (i=1,2,….k). the mean $\bar{x}$, the Range Ri and the standard deviation Si for the ith sample are given by.

$\bar{x}i = \frac{1}{n}\sum xij$

Ri = Max xij –Min xij

$S^2_i = \frac{1}{n}\sum(xij - \bar{x}ij)^2$

Next we find $\bar{x}, \bar{R}$ and $\bar{S}$, the average sample means, sample ranges and sample standard Deviations respectively as follows:

$\bar{\bar{X}} = \frac{1}{k}\sum \bar{x}i$

$\bar{R} = \frac{1}{k}\sum Ri$

$\bar{S} = \frac{1}{k}\sum Si$

4. Setting of control Limits:

It is well known that if σ is the process S.D (S.D of the universe from which samples are taken) then the S.E of the sample Mean is $\sigma/\sqrt{n}$ (i=1,2, …k)

Also from the sampling distribution of range we know that E(R)=d2. σ

Where d2 is a constant depending up on the sample size. Thus an estimate of sigma can be obtained from $\bar{R}$ = d2 , sigma $\Rightarrow \bar{R}/d2$, Also $\bar{x}$ gives the best unbiased estimate of the population mean μ since E($\bar{x}$) = $\frac{1}{k}\sum E(xi) = \mu$

CONTROL LIMITS FOR $\bar{X}$ – *CHART*

Case-1 When standards are given ie., both μ and ±are known the 3 σ control limits for x̄- chart are given by E(x̄) ± 3 S.E ($\bar{R}$) = μ ± $\frac{3\sigma}{\sqrt{n}}$ = μ ± A σ , where A= 3/$\sqrt{n}$

If ́μ and $\acute{\sigma}$ are known or specified values of μ and σ respectively then

UCL x̄ = ́μ + A $\acute{\sigma}$

LCL x̄ = ́μ - A $\acute{\sigma}$

Case-2 If standardards not given: if both μ and σ are unknown then using their estimates x̄ and σ given respectively we get the 3σ control limits on the x̄ as

x̄ ± **3** $\frac{\bar{R}}{\mathbf{d2}}\frac{\mathbf{1}}{\sqrt{n}}$ **=** $\bar{\bar{X}}$ ± ($\frac{3}{d2\sqrt{n}}$) $\bar{R}$ = $\bar{\bar{X}}$ + A2 $\bar{R}$ since A2 = $\frac{3}{d2\sqrt{n}}$

UCL x̄ = $\bar{\bar{X}}$ +A2 $\bar{R}$

LCL x̄ = $\bar{\bar{X}}$ – A2 $\bar{R}$

Since d2 Is a constant depending on n, A2 = $\frac{3}{d2\sqrt{n}}$ *also depends only on′n′* and its value have been computed and tabulated for different values of 'n' from 2 to 20.

Control Limits R- Chart

3σ Control limits for R-chart are given by E($\bar{R}$) ± 3 σ_R

E (R) is estimated by $\bar{R}$ and σ_R is estimated from the relation

σ_R = k E($\bar{R}$) = k $\bar{R}$, where k is a constant depending on 'n'

There fore UCL $\bar{R}$ = $\bar{R}$ + 3K $\bar{R}$ =(1 + 3K) $\bar{R}$ = D4 $\bar{R}$

LCL $\bar{R}$ = $\bar{R}$ - 3K $\bar{R}$ =(1 - 3K) $\bar{R}$ = D3 $\bar{R}$

Where the values D4 = 1+3k and D3= 1-3k have been tabulated for different values of 2 to 20.

5. Construction of control chart for x̄ and R ie. Plotting of control line and control limits. Control charts are plotted on a rectangular coordinate axis – vertical scale (ordinate) representing the statistical measures x̄ and R and horizontal scale (abscissa) representing the sample number. Hours , dates or lot numbers may also be represented on the horizontal scale. Sample points (statistics) are indicated on the chart by point, which may or may not be joined.

Criteria For Detecting Lack Of Control In x̄ And R- Charats

The main object of control chart is to indicate when a process is not control. The following situations depict lack of control.

1.A point outside the control limits: A point going outside control limit is a clear indication of the presence of assignable causes of variation which must be searched and corrected.

2. A run of seven or more points: Although all the sample points are with in control limits usually the pattern of points in the chart indicates assignable causes. One such situation is a run of 7 or more points above or below the central line in the control chart. Such runs indicate shift in the process level. On R –chart a run of points above the central line is indicative of increase in process spread and therefore represents an undesirable situation, while a run below the central line indicates and improvement in the sense that the variability has been reduced. while., the process could hold to a clear tolerance

3.One or more points in the vicinity of control limits or a run of points beyond some secondary limits example a run of 2,3 points beyond 2 σ limits or a run of 4,5 points beyond 1σ limits .

4. The sample points on x̄ and $\bar{R}$ -charts , too close to the central line, exhibit another form of assignable causes.

5. Presence of trends: The trends exhibited on the control chart are so an indication of assignable cause. Trend pattern of raising and falling points continuously a phenomenon usually observed in engineering industry. Trend may be upward or down word.

6. Presence of cycles: In some cases the cycle pattern of points in the control chart indicates a presence of assignable causes. Such pattern area due to material or/and mechanical reasons.

Interpretations of $\bar{x}$ and R charts

In order to judge if a process is in control $\bar{x}$ and R charts should be examined together and the process should be deemed in statistical control if both the charts show a state of control. We summarize below, in a tabular form, such different situations and interpretation to be accorded to reach.

S.No	R-chart	Situations in $\bar{x}$ chart	interpretation
1	In control	Points beyond limits only on one side	Level of process has shifted
2	In control	Points beyond limit on both sides	Level of process in changing in erratic manner –frequent adjustments
3	In control	Points beyond limits on both sides	Variability has increased
4	In control	Out of control on one side	Both level of variability has changed
5	In control	Run of 7 or more points on one side of central line	Shift in process level
6	In control	Trend of 7 or more points. No point out side control limit	Process level is gradually changing
7	Run of 7 or more points above central ling	--------	Variability has increased
8	Points too close to central Line	---------	System difference with in sub-groups.
9	--------	Points too close to the central line	System difference with in sub-groups.

Average Run Length

A point will occasionally plot outside the 3σ limits even when the process is in control. This is called ***false alarm .*** It can also happen that a process that is not in control may not exhibit any points out side the control limits. This is called ***failure to detect***

It is desirable for these errors to occur infrequently as possible. We describe the frequency with which these errors occur with quality called AVERAGE RUN LENGTH (ARL). The ARL is the number of samples that must observed, on average, before a point plots out side the control limits. We would like the ARL for an $\bar{x}$ chart if we assume that process mean μ and process S.D (σ) are known. Then the centre line is located at the process mean μ and the control limits are $\mu \pm 3\sigma$ .We must assume, as in always the case with $\bar{x}$ chart, that the quantity being measured is approximately normally distributed.

Example: for $\bar{x}$ chart with control limits $\mu \pm 3\sigma$, compute the ARL for a process that is in control.

Situation: Let $\bar{x}$ be the mean of the sample than $\bar{x} \sim N(\mu, \sigma^2)$. The probability that a point plots outside the control limits is equal to $P(\bar{x} < \mu - 3\sigma) + ((\bar{x} > \mu + 3\sigma)$. This probability is equal to 0.00135+0.00135=0.0027, Therefore the average 27 out of every 10,000 points out side the control limits.. This is equivalent to 1 every 10,000/27=370.4 points. The ARL is therefore equal to 370.4. The above result can be interpreted as follows. If a process is in control, we expect to observe above 370 samples, on the average, before finding one that plots outside the control limits, causing a false alarm. Note also that the ARL in the above example 10,000/27, which is equal to 1/0.0027, where is the probability that same of out side the control limits ARL=1/p

System of Reliability

System of Reliability is defined as the probability that the finished product will function properly given that it is assembled from components which are less than perfect.

Most items have a number of components in it. Even a ball pen has a micro ball, ink, cartridge, spring, a devise to push the writing ball out and then retract it and so on. Each component has some probability that it is not perfect. Accordingly, the reliability of system (that the pen work perfectly) is function of reliability of each of its components. The reliability system is determined by

$R_s = (R_{1)}.(R_{2)}.(R_{3)}\ldots.(R_{n)}$

Where Rs=Reliability of the system

Rn= Reliability of the nth component.

Assume that a light bulb has 3 components, namely, a switch, a plug and a bulb. All these components must work properly for the bulb to light. Assume further that each component has 97% reliability. This means that only 3% of each of these components are known to be defective that .Then

$R_s = R_1.R_2.R_{3 = (}.97)\ _{(}.97)\ _{(}.97) = 0.913$

Thus above 9% of the lamps will fail and about 91% of the lamps will work properly.

The reliability of the complex item drops rapidly as the number of components in that item increases. For example, a system with 5 components with each component being 97% reliable, will have the reliability of $R_s = R_1.R_2.R_3.R_4.R_5$ =(.97) (.97) (.97) (.97) (.97)=0.859

With 10 components in the system of similar reliability, the system reliability decreases to 0.737.

To combat this problem, the manufacturers use two primary strategies. These are as follows.

1.Quality is built in the design of the element with an ultimate goal of zero defect per unit.

2.For crucial elements, a backup component is added to system so that if the component fails, the back up component prevent system failure. For example, the hood of a car has a double latch so that the first latch malfunctions, the second back-up latch will stop the hood from automatically opening.

Design of Experiments In Statistical Quality Control

The design of experiments may be used to help improve the capacity of a process by identifying the process and product variables that effect the mean ad variance of the quality characteristics of the product. It can help in improving process yields. The variables that affect the out put variables are divided in to two groups.

1. Input variables or single factors
2. Noise variables.

1.Input variables or single factors: Input variables or single factors can be controlled during experiments and at the design stage and /or in the actual production stage.

2.Noise variables: Noise variable factor either can not be controlled or are difficult and/or expensive to control during design or actual production stage. Some examples of these factors are the composition of raw materials used in manufacture and the humidity level in production shop. But these variables could be controlled but only at considerable cost.

Other variables: A third type of variable which includes variables that are functions of input variables and affect the output variables, is called ***intermediate variable***. The out put variable that is being studied and measured in an experiment is the ***response variable***. Identifying the input variables, intermediate variables, noise variables is a critical step in any experiment and can be effectively performed using cause-and - effect - diagrams.

Replication: Experiment runs under identical conditions should be replicated in sufficient number of times to obtain accurate estimates of experimental errors and the effects of input variables on the response variables.

Randomization: The order of assigning objects or components to the levels of factors and experimental runs should be randomized as much as possible in order to balance out the effect of noise variables on the response variables, to minimize the bias, and no introduce independence among the observations of the response variable. This may be easy to or feasible in all experiments.

Multivariate Process Monitoring and Control

Work out: The data shown her come from a production process with two observable quality characteristics, x1 and x2. The data sampled means of each quality characteristics, based on the sample size n=25. Assume that mean values of the quality characteristics and the covariance matrix were computed from m=50 preliminary samples.

$\bar{\bar{X}} = \begin{pmatrix} 55 \\ 30 \end{pmatrix}$, s= $\begin{pmatrix} 200 & 130 \\ 130 & 120 \end{pmatrix}$

Sample	$\bar{x}1$	$\bar{x}2$	T^2
1	58	32	1.1268
2	60	33	3.1690
3	50	27	3.1690
4	54	31	2.0423
5	63	38	13.5211
6	53	53	1.6909
7	42	42	22.8269
8	55	55	0.7042
9	46	46	10.6383
10	50	50	6.6901
11	49	27	5.0704
12	57	30	1.6901
13	58	33	1.9014
14	75	45	52.8169
15	55	27	6.3380

Phase-2 charts arte used for monitoring future production, as compared to phase-I limits, that are used for retrospective analysis of data. For univariate charts such as $\bar{x}$ -chart, the distance between phase –I and Phase-II control limits is usually unnecessary for more than n=20 or 25 samples. More care should be exercised for multivariate charts.

Design Phase-II Control charts m=50 preliminary samples, n=25, p=2 characteristics, Let $a = 0.001$ using the text equation.

$$\text{U.C.L} = \frac{p(m+1)(n+1)}{mn-m-p+1} F_{a,\ mn-m-p+1} = \frac{2(50+1)(25-1)}{50(25)-50-2+1} F_{0.001} = \frac{2448}{1199}(6.948)$$

$$\text{UCL} = 14.186\ ,\ \text{L.C.L} = 0$$

$$N= 25,\ \overline{\overline{X1}} = 55,\ \overline{\overline{X2}} = 30,\ s_1^2 = 200,\ \ s_2^2 = 120,\ S_{12} = 130\backslash$$

$$\text{SAMPLE}\ \ \overline{x1} = 58, \overline{x2} = 32,\ \ \overline{x1} = (58\ ,\ \ 32)$$

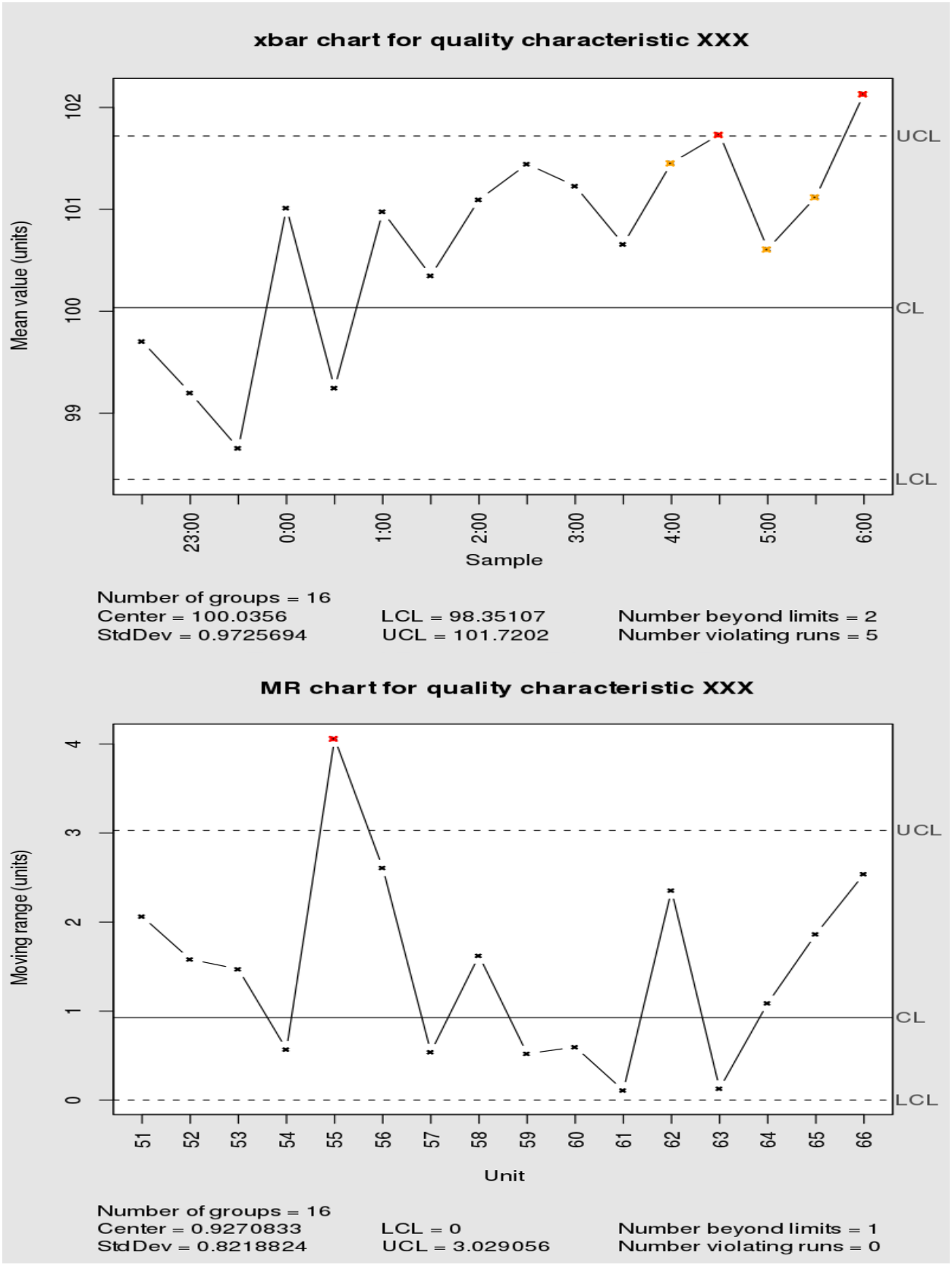
$$T_1^2 = n(\overline{x1} - \overline{\overline{X1}}\ )\ \overline{s1}\ \ (\overline{x1} - \overline{\overline{X2}}\ )$$

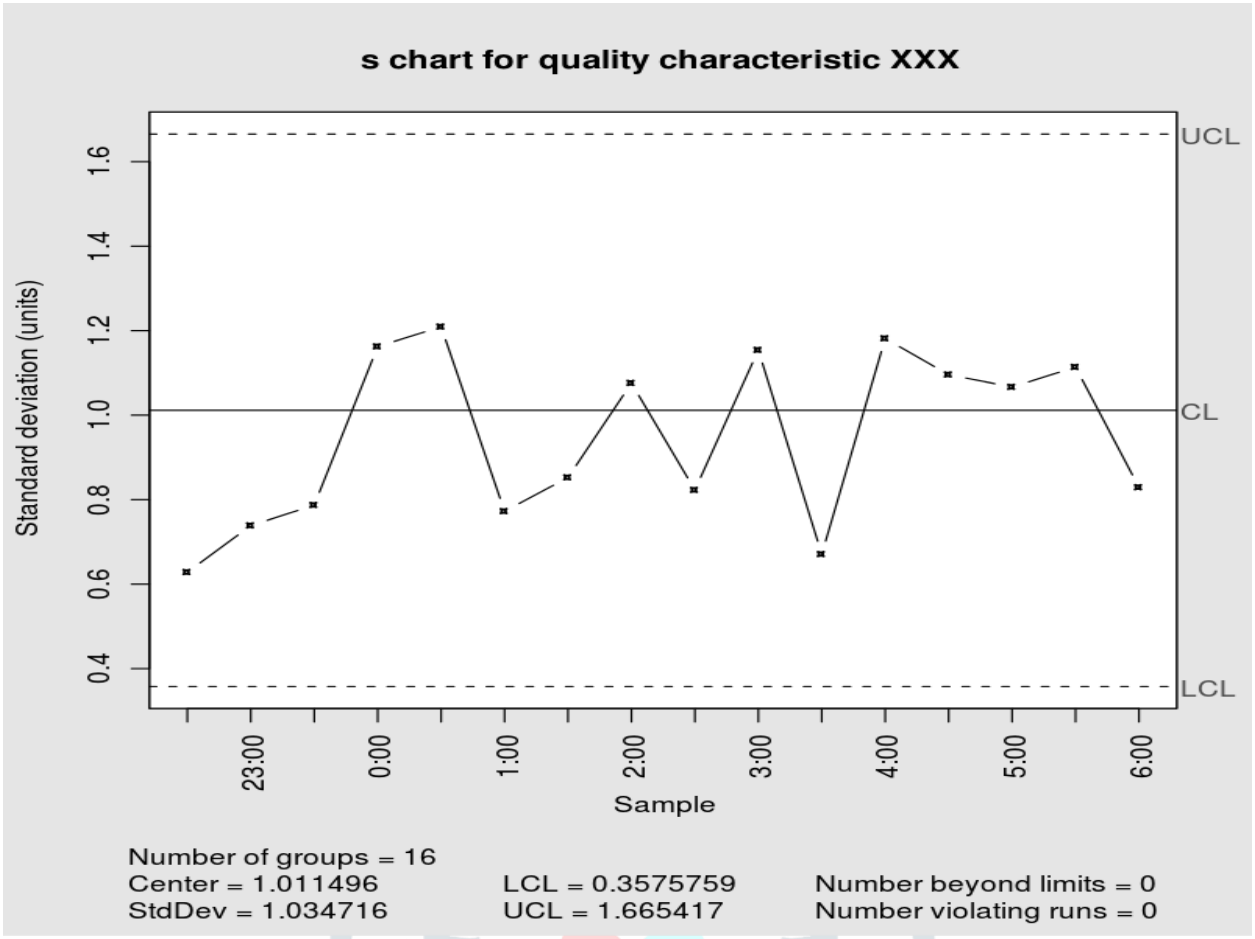
$$= \frac{n\ \{\ s_2^2\ (\overline{x1} - \overline{\overline{X2}}\ )^2 + s_1^2\ (\overline{x2} - \overline{\overline{X2}}\ )^2 - 2(s_{12})\ (\overline{x1} - \overline{\overline{X1}}\ )(\overline{x2} - \overline{\overline{X2}}\ )}{\{(\ s_1^2\ \ s_2^2\ ) - (s_{12}^2)}$$

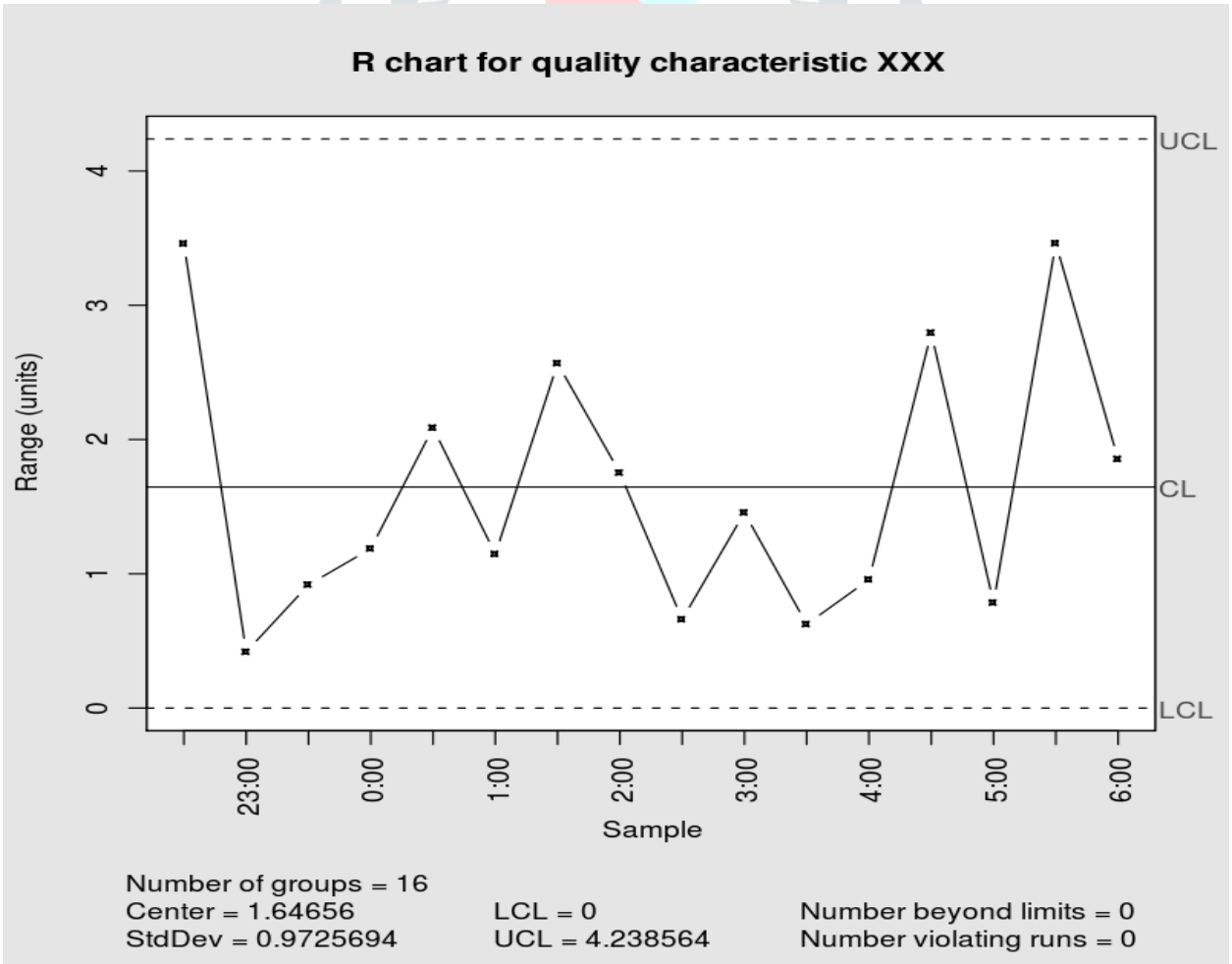
$$= 1.1268$$

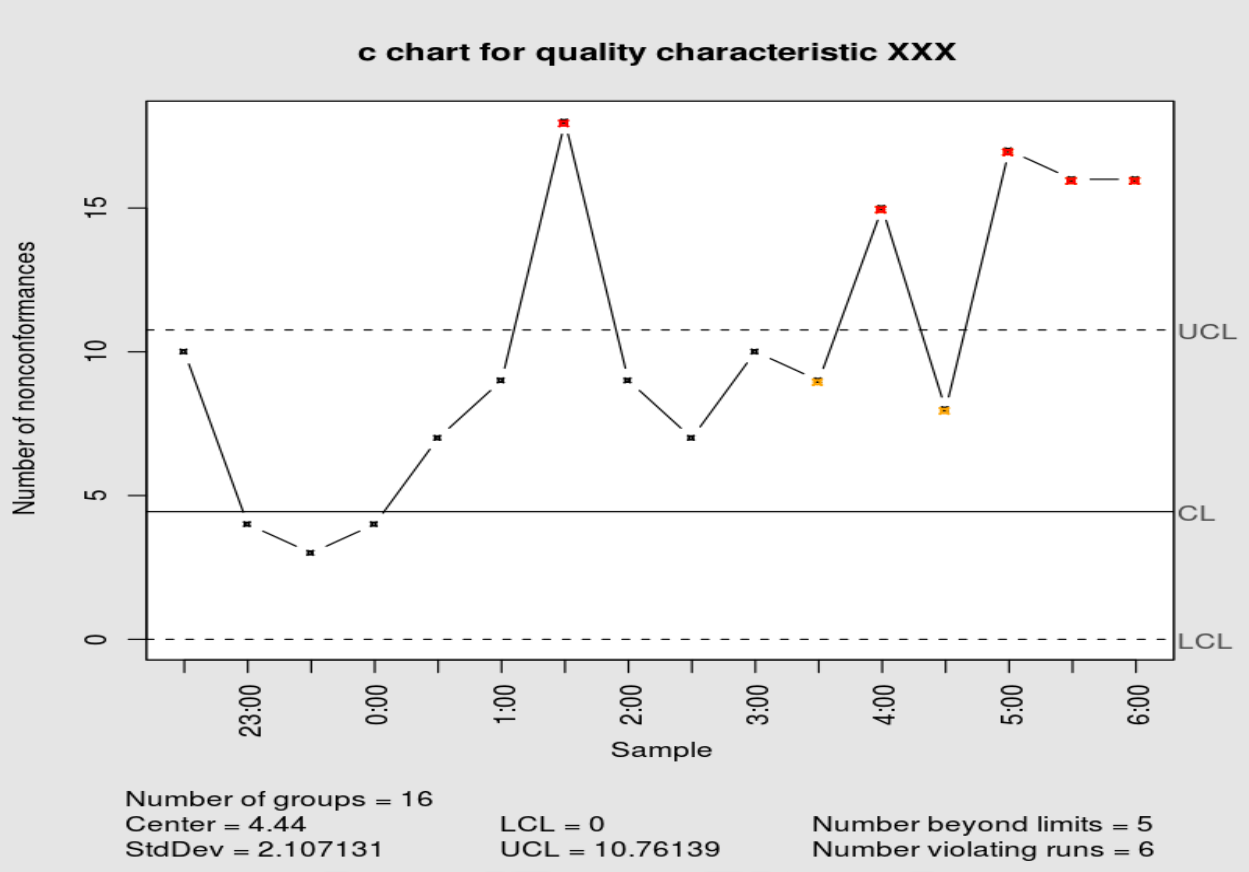
The process signals out of control samples 7 and 14.

Various Statistical Quality control charts at a glance


xbar chart for quality characteristic XXX
Mean value (units)
102
101
100
99
UCL
CL
LCL
23:00
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Sample
Number of groups = 16
Center = 100.0356
StdDev = 0.9725694
LCL = 98.35107
UCL = 101.7202
Number beyond limits = 2
Number violating runs = 5
MR chart for quality characteristic XXX
Moving range (units)
4
3
2
1
0
UCL
CL
LCL
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
Unit
Number of groups = 16
Center = 0.9270833
StdDev = 0.8218824
LCL = 0
UCL = 3.029056
Number beyond limits = 1
Number violating runs = 0


s chart for quality characteristic XXX
Standard deviation (units)
0.4
0.6
0.8
1.0
1.2
1.4
1.6
UCL
CL
LCL
23:00
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Sample
Number of groups = 16
Center = 1.011496
StdDev = 1.034716
LCL = 0.3575759
UCL = 1.665417
Number beyond limits = 0
Number violating runs = 0


R chart for quality characteristic XXX
Range (units)
0
1
2
3
4
UCL
CL
LCL
23:00
0:00
1:00
2:00
3:00
4:00
5:00
6:00
Sample
Number of groups = 16
Center = 1.64656
StdDev = 0.9725694
LCL = 0
UCL = 4.238564
Number beyond limits = 0
Number violating runs = 0



Conclusion

In summary, SQC is a powerful methodology that ensures consistent product quality by analyzing variations and distinguishing between random and assignable causes. By employing statistical techniques such as control charts, process capability analysis, and sampling, organizations can proactively manage quality and minimize defects. Remember that SQC is an essential tool for maintaining high standards and meeting customer expectations in various industries.

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