

At times, the main cause is hidden and we may still find that efficiency is low and there are a lot of dissatisfied customer.

Do not be content with this condition. Aim for even higher goals and keep taking up preventive measures. That is what QC Problem-Solving is all about.

**7 QC Tools.** The Samurai warrior had seven tools, such as a sword, helmet, bow guard and arrow and so on ; he would never venture any where without these tools, which he needed for protection and success. In a similar vein, the seven quality control tool are essential for to-day's workers, engineers, professionals, and managers.

**1. Pareto Diagram.** The Pareto principle was named after the Italian economist who had developed certain mathematical relationships of vital few and trivial many as applied to distribution of wealth. In studying the problems, it can be generally observed that 80% of the problems result from only 20% of the potential causes.

The primary purpose and use of pareto diagrams is to focus improvement efforts on the most important causes by identifying the vital few and trivial many causes.

The Pareto Chart Indicates the following :

1. What are the problems,
2. Which problem needs to be tackled on priority.
3. What percentage (%) of the total does each problem present.

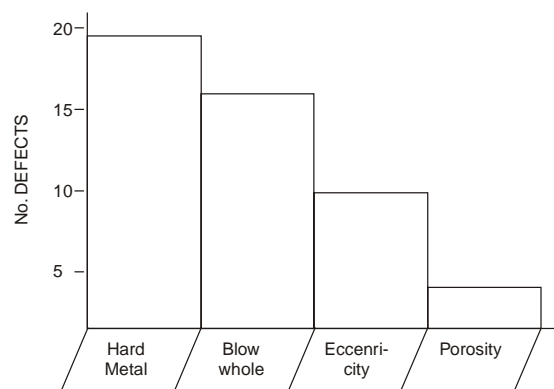
#### Areas of Application

Sales	— Customer complaints analysis, warranty costs, Market Share
Production	— Analysis of Non-conformance, machine and men Utilization
Maintenance	— Machine down time, break down, spares requirement.
Safety	— Injury types and causes
Finance	— Costs, etc.

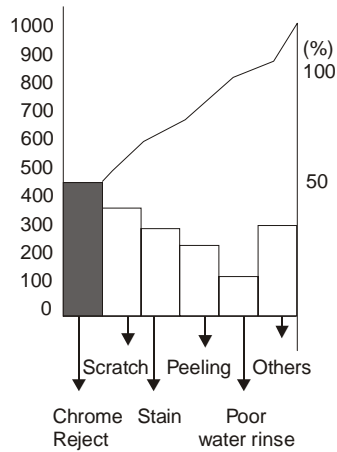
How to construct Pareto Diagram

1. Select the problem area (say customer complaints).
2. Decide the method and the period for data collection.
3. Arrange the data of the items in the descending order.
4. Draw axis on graph with the scale of unit indicated.
5. Draw the bar graph in the descending order.

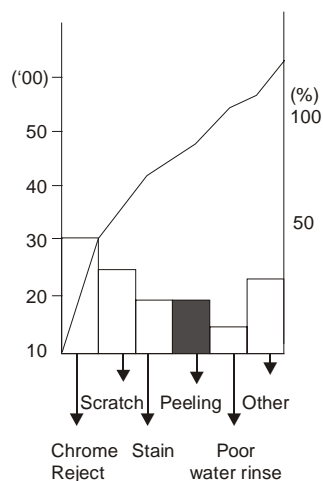
Defects in Casting revealed After machining



Pareto Diagram (A)



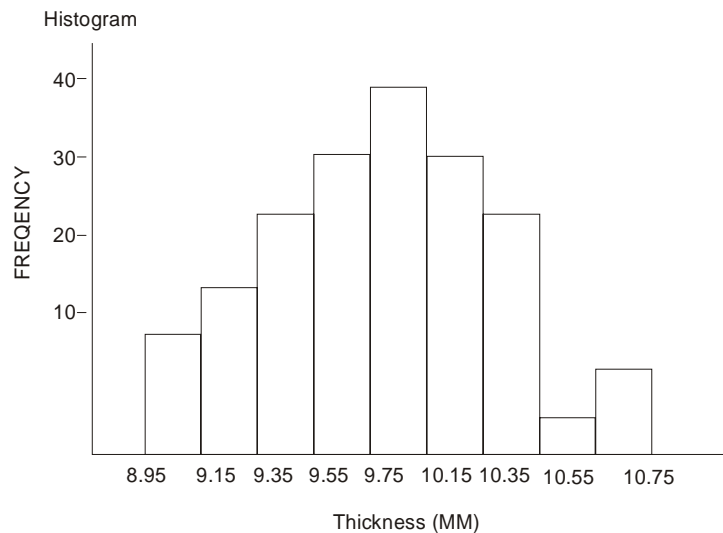
Pareto Diagram (B)



**2. Histogram.** A histogram is a bar graph which shows the frequency distribution of the data of a group about the central value. The histogram is an important diagnostic tool because it gives a “Birds’s-eye-view” of the variation in a data set.

A histogram can be used for

1. Comparisons of process distribution before and after the improvement action (production, vendor performance, administration, purchase, inspection, etc.)
2. Comparison of different groups (production, vendor to vendor difference etc.)
3. Relationship with specification limits.



**3. Cause and Effect Diagram.** A cause and effect diagram (also known as Ishikawa diagram or fishbone diagram) is a pictorial representation of all possible causes which are supposed to influence an “effect” which is under consideration.

For every effect there are likely to be several causes. They can be classified under men, methods, materials, machines, policies, procedures, plant etc. These categories are only suggestions. You may use any category that emerges or helps people think creatively.

#### **Steps in Constructing a Causes and Effect Diagram**

Address to the member the problem or the “Effect” in question and ask the members what the possible causes could be adopt structured brain storming method (in brain storming encourage ideas, never criticise, allow to develop on other ideas, write all ideas on a flip chart or black board).

Start constructing the diagram. Write the effect or the problem on the right hand side in a rectangular box.

Cluster the causes of the effect under large heading and write against bones.

#### **Interpretation of C and E Diagram**

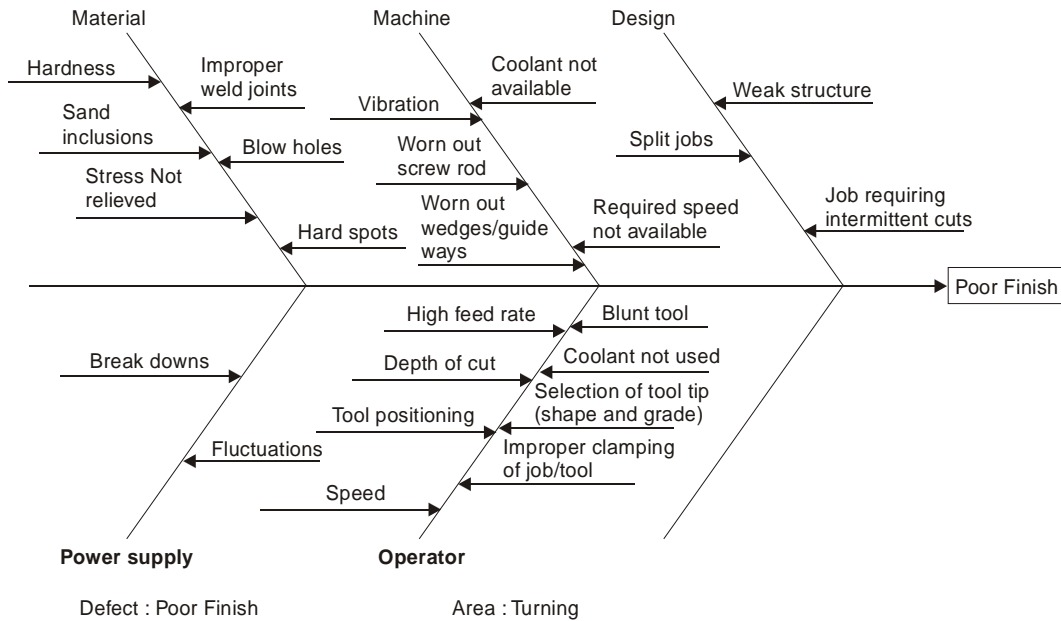
In order to find most basic cause of the problem

Look for causes that appear repeatedly.

Reach a team consensus

Gather data to determine the relative frequencies of the different causes.

**Cause and Effect Diagram**



**4. Check Sheet**

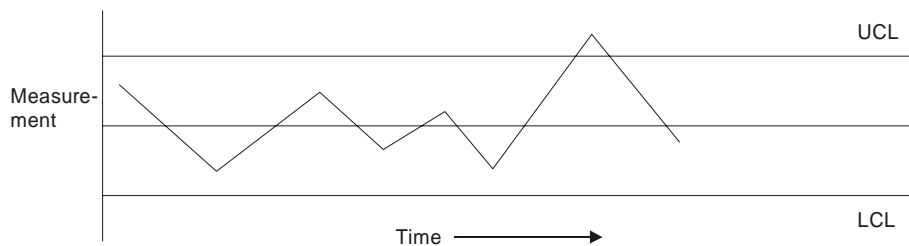
A check sheet is a data gathering format prepared in such a way that the data collection is simplified.

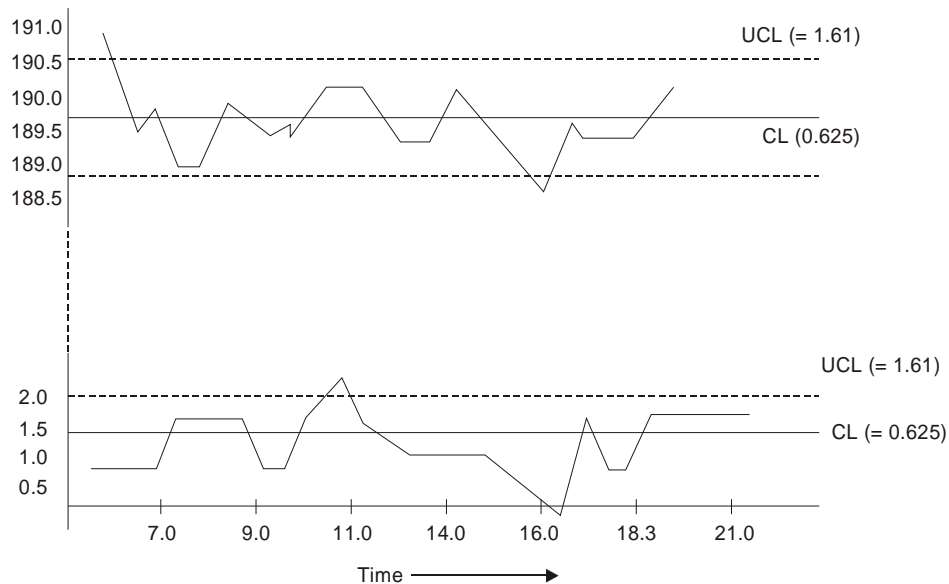
The check sheet preparation considers the representatives of the information to be recorded and simplifies the data that is to be actually recorded everytime to a mere check work. Check sheets are simply an easy to understand form used to answer the question “how often certain events are happening” ? It starts the process of translating into facts.

**5. Control Chart**

A control chart is a chart to examine whether a process is in stable condition or to ensure that process is maintained in stable condition.

The control limits are indicated by two line viz. Upper control limit and lower control limit. If the points are within the control limit lines, then the process is in stable condition. The fluctuation of the points within the control limit line results from common causes built into the process. However points outside the limits come from a special cause.





## 6. Stratification

Stratification is the technique of obtaining data in different groups based on segregated causes.

In general the poor quality is resulted due to the influence of multiple causes. To identify the principle cause of poor quality it is necessary to collect the data in different groups according to the different causes.

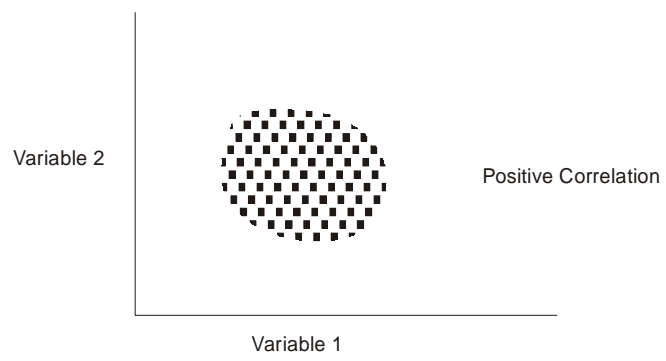
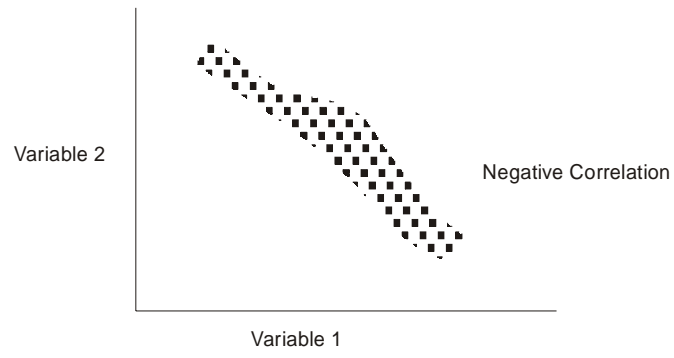
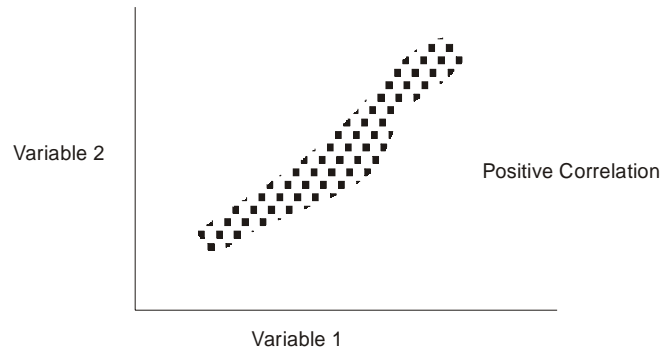
### Areas of Application

- Raw Material — Supplier wise stratification  
Batch wise stratification
- Production — Machine wise stratification  
operator wise stratification shift wise
- Finance — Stratification of income and expenditure as per different categories.
- Safety etc., — Accident type wise stratification.

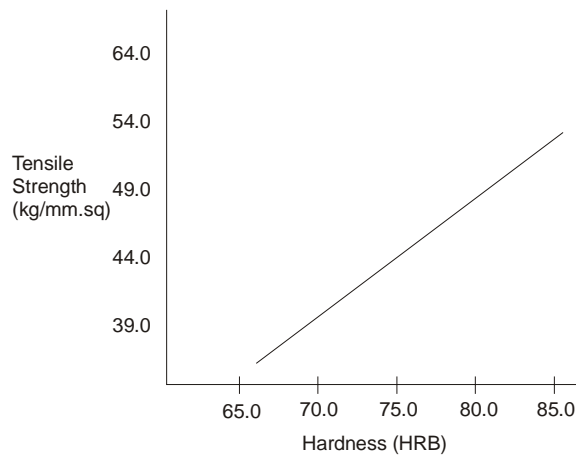
## 7. Scatter Diagram

Scatter diagram is a simple statistical tool to understand in a better way the relationship between two variables.

It makes clear whether a relationship exists between two variables and the strength of that relationship.



### Scatter Diagram



### Causes of Variation in Quality

The variation in the quality of the product in any manufacturing process is broadly classified into two classes : Chance causes and Assignable causes.

#### Chance Causes

The chance causes are those causes which are inherent in manufacturing process by virtue of operational and constructional features of the equipments involved in a manufacturing process. This is because of :

- (1) Machine vibration
- (2) Voltage fluctuation
- (3) Temperature fluctuation
- (4) Tool Chatter
- (5) Composition variation of material etc.

The chance causes are very difficult to trace out, even though it is possible to trace out, it is not economical to eliminate. The chance causes results in only a minute amount of variation in process.

Variation in the chance causes is due to internal factors only. The general pattern of variation under the chance causes will follow a stable statistical distribution (Normal distribution).

#### Assignable Causes

These are the causes which creates an extraordinary variation in the product quality. Assignable causes variable can always be traced to a specific source. Assignable causes occur due to

- (1) Lack of skill in operation
- (2) Wrong maintenance practices
- (3) New vendors

(4) Errors in setting jigs and fixtures

(5) Raw materials defect etc.

Variation due to these causes can be controlled before the defective items are produced. Any one assignable cause can result in a amount of variation in process. If the assignable causes are present, then system will not follow a stable statistical distribution.

### CONTROL CHARTS

**Definition.** A control chart is defined as a statistical tool used to detect the presence of assignable causes in any manufacturing systems and it will be influenced by the pure system of chance causes only.

Control charts are of two types : Variable control charts and Attribute control charts.

#### Variable Control Charts

A variable control chart is one by which it is possible to measure the quality characteristics of a product. The variable control charts are

(i)  $\bar{X}$  — chart

(ii) R — chart

(iii)  $\sigma$  — chart

#### Attribute Control Chart

An attribute control chart is one in which it is not possible to measure the quality characteristics of a product *i.e.*, it is based on visual inspection only like good or bad, success or failure, accepted or rejected. The attribute control charts are !

(i)  $p$  — chart

(ii)  $np$  — chart

(iii)  $c$  — chart

(iv)  $u$  — chart

#### Objectives of Control Charts

1. Control charts are used as one source of information to help whether an item or items should be released to the customer.
2. Control charts are used to decide when a normal pattern of variation occurs, the process should be left alone when an unstable pattern of variable occurs which indicates the presence of assignable causes it requires an action to eliminate it.
3. Control charts can be used to establish the product specification.
4. To provide a method of instructing to the operating and supervisory personnel (employees) in the technic of quality control.

Symbols or Notations

$\bar{X}$  : Mean of the sample

$\bar{X}^\sigma$  : Standard deviation of the sample

$\bar{X}^1$  : Mean of the population or universe

$\sigma^1$  : Standard deviation of the population.



9. Poka-Yoke to prevent or detect errors.
10. Team dynamics. Which includes problem solving, communication skills and conflict resolution.

Kaizen realies heaving on a culture that encourage suggestions by operators who continually try to incrementally improve their job or process. This change results in a small improvement in weld quality and a substantial improvement in oprator satisfaction. The PDSA cycle described earlier may be used to help implement Kaizen concepts.

### Reengineering

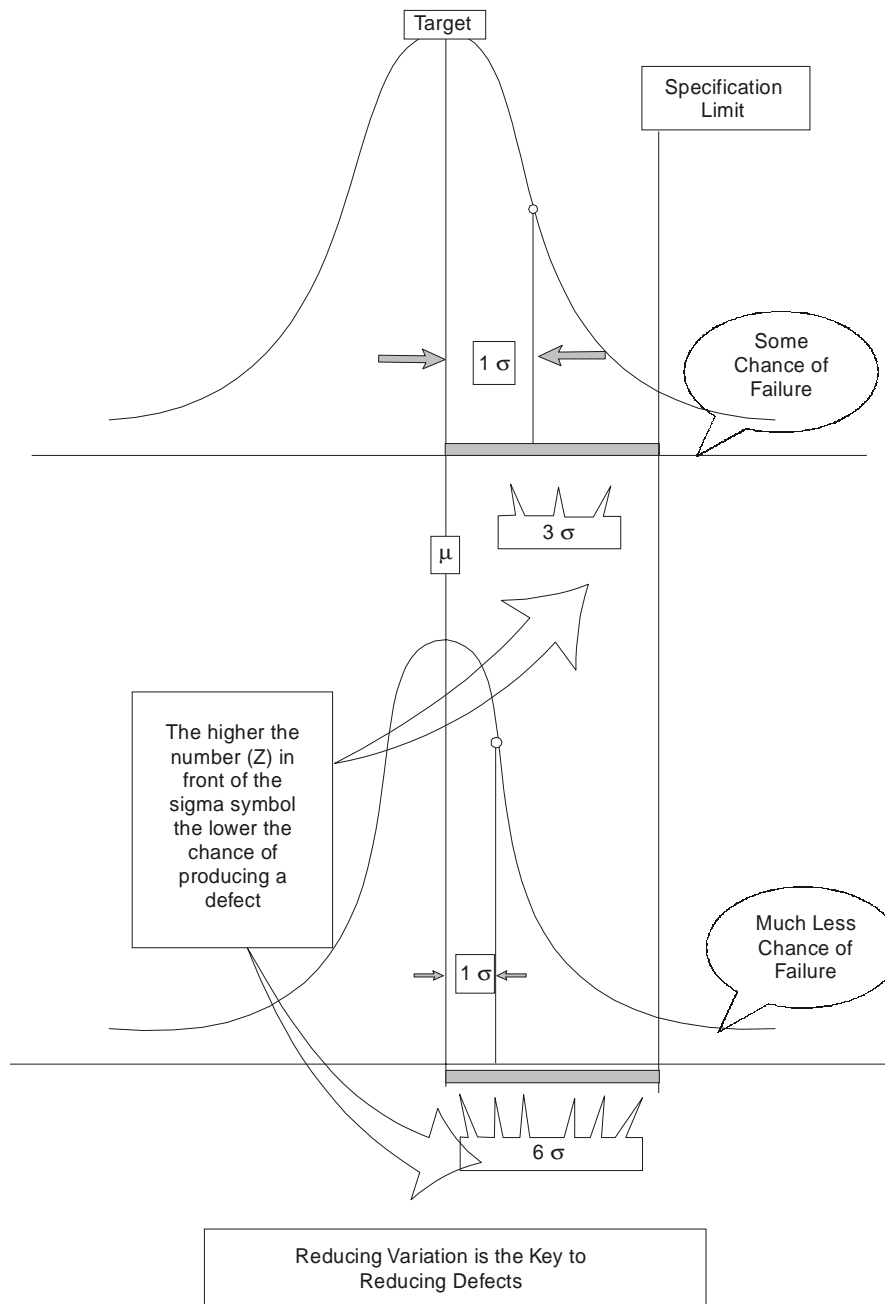
According to Hammer and Champy reengineering is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical measures of performances. Many practitioners believe that TQM is associated with only incremental in provements. The Japanese have not only relied on Kaizen but have developed policy management (host in kanri) and policy deployment (hostin tenkai) in large part to product the kind of large-scale break through that Hammer and Champy promote. Clearly there is nothing new in the reengineering concept. It has always been part of the TQM umbrella.

## SIX SIGMA (6 $\sigma$ ) QUALITY

### An Overview

'Sigma' is used to designate the distribution or spread about the mean (average) of any process. Sigma ( $\sigma$ ) is another word for standard deviation. For a business or manufacturing process, the sigma value is a metric that indicates how well that process is performing. The higher the sigma value, (2 $\sigma$ , 3 $\sigma$ , 4 $\sigma$  etc.) the better the process. Sigma measures the capability of the process to perform defect-free-work. A defect is anything that results in customer dissatisfaction. With 6 $\sigma$ , the common measurment index is 'defects-per-unit', where unit can be virtually anything—a component, a piece of a material, a line of code, an administrative form, a time frame, a distance, etc. **The sigma value indicates how often defects are likely to occur. The higher the sigma value, the less likely a process will produce defects. As sigma value increases, costs go down, cycle time goes down, and customer satisfaction goes up. A 6 $\sigma$  process simply means that between the target specification and the tolerance limit six standard deviations can be fitted-in,** (Fig. 4.7 explains clearly the difference between the 3 $\sigma$  and the 6 $\sigma$  process). Further, a 6 $\sigma$  process capability means 3.4 ppm defects or 99.99966% good.

Our process is the reality. When we draw the histogram of our process output we come to know how we are ; we can, then, calculate the sigma ( $\sigma$ ) value of our process. When we place the tolerance limits, as decided by the competition, on our curve (normally distributed) we come to know where we are. We may be at 2 $\sigma$  or 3 $\sigma$ , etc. We now start our journey towards 6 $\sigma$ . **In other words we have to shrink the variability of our process to such an extent, that the value of sigma of the process reduces to a new low, which can be fitted  $\pm 6$  times within the same tolerance limits.** This is Quality Improvement. Such an improved process hardly produces any defect.

What is 6 $\sigma$  ?

**Fig. 4.7.** Difference between 3 $\sigma$  and 6 $\sigma$  process.

### The Practical Meaning of

<i>99% Good (3.8<math>\sigma</math>)</i>	<i>99.99966% Good (6<math>\sigma</math>)</i>
<ul style="list-style-type: none"> <li>• 20,000 lost articles of mail/hour</li> <li>• Unsafe drinking water 15 min./day</li> <li>• 5,000 incorrect surgical procedures/week</li> <li>• 2 short or long landings at airports/day</li> <li>• 200,000 wrong drug prescriptions/year</li> <li>• No electricity for almost 7 hours/month</li> </ul>	<ul style="list-style-type: none"> <li>• Seven articles lost/hour</li> <li>• Unsafe drinking water 1 min./7 months</li> <li>• 1.7 incorrect surgical procedures/week</li> <li>• One short or long landing/5 years</li> <li>• 68 wrong prescription/year</li> <li>• One hour without electricity/34 years</li> </ul>

### Six $\sigma$ As a Goal

(Distribution shifted  $\pm 1.5\sigma$ )

<i>Sigma level</i>	<i>Defects in PPM</i>	<i>Yield in %</i>
2 $\sigma$	308,538	69,1462
3 $\sigma$	66,807	93,3193
4 $\sigma$	6,210	99,3790
5 $\sigma$	233	99,9767
6 $\sigma$	34	99,99966

### 6 $\sigma$ According to Dr. Mikel J. Harry, CEO of Six Sigma Academy, Phoenix, USA

- ☆ **First, it is a statistical measurement.** It tells us how good our products, services and processes really are. It allows us to draw comparisons with other similar or dissimilar products, services and processes. We can see where we need to go and what we must do to get there. In other words, 6 $\sigma$  helps us establish our course and gauge our pace in the race for total customer satisfaction.
- ☆ When we say a process is 6 $\sigma$ , we are saying it is best in class. Such a level of capability will only yield 3.4 instances of nonconformance out of every million opportunities for nonconformance. On the other hand, when we say that some other process is 4 $\sigma$ , we are saying it is average. This translates to 6,210 non-conformities per million opportunities for nonconformance. In this sense, the sigma scale or measure provides us with a “goodness micrometer” for gauging the adequacy of our products, services and processes.
- ☆ **Second, it is a business strategy.** It can greatly help us gain a competitive edge. The reason for this is very simple — as you improve the sigma rating of a process, the product quality improves and costs go down. Naturally, the customer becomes more satisfied as a result.
- ☆ **Third, It is a philosophy.** It is an outlook, a way that we perceive and work within the business world around us. Essentially, the philosophy is one of working smarter, not harder. This translates to making fewer and fewer mistakes in everything we do — from the way we manufacture products to the way we fill out a purchase order. As we discover and neutralize harmful sources of variation, our sigma rating

goes up. Again, this means that our process capability improves and the defects (mistakes) go away.

### **6 $\sigma$ According to Mr. Jack Welch, The CEO of The General Electric Co., USA :**

- ☆ 6 $\sigma$  is a disciplined Quality Improvement methodology that focuses on moving every process that touches the customers — every product and service — towards near perfect Quality. It is a measure of the Company's Quality.
- ☆ 'MOTOROLA' pioneered it and 'ALLIED SIGNAL' successfully embraced it. GE took the experiences of these two companies and started implementing it.
- ☆ 6 $\sigma$  is a top-down system.
- ☆ If you have to successfully implement 6 $\sigma$ , the Company should be
  - Open to change
  - Hungry to learn and
  - Anxious to move quickly on a good idea
- ☆ We became convinced that 6 $\sigma$  qualities could play a central role in GE's future, but we also know that it would take years of consistent communication, relentless emphasis and impassioned leadership to move GE on this bold new course.
- ☆ Today, '6 $\sigma$ ' has spread like wildfire across the company and it is transforming everything we do. It has saved around 1200 million dollars to the company during 1998.
- ☆ '6 $\sigma$ ' is quickly becoming a part of the genetic code of our future leadership. '6 $\sigma$ ' training is now an ironclad pre-requisite for promotion to any professional or managerial position in the company — and a requirement for any award of stock options. Senior Executive compensation is now heavily weighted toward 6 $\sigma$  commitment and success-success now increasingly defined as "eatable" financial returns, for our customers and for us.
- ☆ We believed that there was an ocean of creativity, passion and energy in GE people that had no bottom and no shores. We also believed that there was an "Infinite capacity to improve everything". We believed these then, but there was no methodology or discipline attached to that belief. There is Now. It is '6 $\sigma$ ' quality, along with a culture of learning, sharing and unending excitement.

### **6 $\sigma$ Breakthrough Methodology of Quality Improvement**

The methodology is not very unique. It is a slight variant of the methodologies given by many quality gurus. There is nothing breakthrough in the methodology as such. But the solutions/results, we obtain by following this systematic methodology are really breakthrough. The improvement is not just in percentages but in manifold (say 100 times, 1000 times etc.)

The methodology consists of five steps namely Define (D), Measure (M), Analyse (A), Improve (I) and Control (C). Brief explanations for the same are as follows.

**Define.** The problem which requires breakthrough solution, has to be defined clearly in measurable terms. The problem selected should be vital to the customer and should have relevance to the company's business. In other words it should ensure great customer satisfaction as well as rupee savings to the company. If the company has developed its Business Strategies, the problem should fall under any one of them. Generally any customer

expects defect free products/services and timely deliveries. Majority of the problems will fall under these two categories. Defining the problem in manufacturing area is easier when compared to service areas.

**Measure.** The second most important step is measurement. We have to measure in terms of numbers to know where we are, and to decide where we go. To quote Dr. Mikel J. Harry — “If you can’t express your process in the form of numbers you don’t really know much about it. And if you don’t know much about it, you can’t control it. And, if you can’t control it, you are at the mercy of chance. And, if you are at the mercy of chance, why bother with it ? Hence we must learn the language of numbers”.

Data is as good as the system that measures it. Hence, before collecting the data a measurement system analysis has to be done and if it is not to the satisfactory level, corrective action has to be taken before measuring the data. Data is of two kinds — Discrete and Continuous. Continuous data is more amenable for Statistical analysis and hence as far as possible attempts should be made to convert the discrete data into continuous data. After collecting the data (discrete) on defects and counting the opportunities to make the defects, we can calculate the defects per opportunity (dpo), which is nothing but the probability of making the defects. From the statistical tables we can find out the corresponding ‘Standard normal deviate’, *i.e.*, the Z value or the sigma value. If it is a continuous data we can find out the sigma value by calculating the mean and the standard deviation of the process and knowing the specification limits. With this we can statistically define the problem.

After defining the problem a cause and effect diagram has to be constructed through brainstorming and segregate the causes into experimental and non-experimental causes. Solutions have to be found and implemented through Standard Operating Procedures (SOP) for the non-experimental causes at this stage itself, which brings down the variability of the process to a great extent. The experimental factors can be carried forward to the next phase-analysis.

**Analyse.** Statistical analysis has to be carried out at this stage to identify the vital experimental causes. Tests have to be conducted to find out whether the causes (factors) really make statistically significant difference in the effects (responses) when the levels of these factors are changed. The tools used are T-test, F-test, ANOVA, Chi-Square, correlation and Regression. A graphical analysis called multi-vari analysis is also done to segregate the variation of the response into with-in piece, between pieces and over time variations. After identifying the vital few experimental factors they have to be carried forward to the next phase-Improve.

**Improve.** In this phase we will be optimizing the response. In other words we will be hitting the target value by experimenting with the level settings of the vital few factors. This is called Design of Experiment. There are various stages like Screening design/fractional factorial design, full factorial, full factorial with replication, Central composite design, Method of Steepest ascent, Evolutionary process (EVOP), Taguchi’s method etc. Finally we will be tolerancing the factors at the required levels. In order to conduct the DOE, thorough planning is necessary, because the DOE is time consuming and sometimes costly.

**Control.** The last phase is to hold the gains that have been obtained from the improve phase. Unless we have good control we are likely to go back to the original state. ‘Statistical Process Control’ (SPC) has to be employed to control the gains. There are various kinds of control charts like I and MR,  $\bar{X}$  and R,  $\bar{X}$  and S and EWMA for continuous data and  $p$ ,  $np$ ,  $c$  and  $u$  charts for discrete data, to choose from. Also POKA-YOKE (mistake-proof) devices

can be set up to obviate the inadvertent errors. The idea of POKA-YOKE is to respect the intelligence of workers by taking over repetitive tasks that depend on vigilance or memory.

### **CONCLUSION**

This article has only tried to explain the meaning of 'six sigma', without going into the depth of statistics. In effect the 'six sigma' Quality improvement methodology is a strategic bridge between the Quality Philosophy and the statistical tools available, which heavily depends on the Management drive and rigorous practice for its sustenance. To be fairly conversant with this methodology, one has to undergo a minimum of 10 days classroom training and then execute at least one real improvement project. Once the methodology is familiar. I am sure, one will not stop improving. 'Six sigma' is not just a fad ; it has yielded rich dividends in companies like MOTOROLA, GENERAL ELECTRIC, ALLIED SIGNAL, etc. It is now catching up in India and I can mention at least two major companies, viz., M/S BHARAT ELECTRONICS LTD and M/S WIPRO, which are rigorously practicing.

what, who, how, where and when of the process and is an up-dating of the monitoring activity. Standardizing the solution prevents 'back sliding'. The quality peripherals. The system, environment and supervision must be certified. The partial check list in provides the means to initially evaluate the peripherals and periodically audit them to ensure the process will meet or exceed customer requirements for the products or service.

Finally, operators must be certified to know what to do and how to do it for a particular process. Total product knowledge is also desirable. Operator certification is an ongoing process that must periodically occur.

#### **Phase 7 : Plan for the Future**

This phase has the objective of achieving improved levels of process performance. Regardless of how successful initial improvement efforts are, the improvement process must continue. It is important to remember that TQM addresses the quality of management as well as the management of quality. Everyone in the organization is involved in a systematic long-term to constantly improve quality by developing processes that are customer oriented, flexible and responsive.

Continuous improvement means not being satisfied with doing a good job or process, but striving to improve that job or process. It is accomplished by incorporating process measurement and team problem solving in all work activities. TQM tools and technique are used to improve quality, delivery and cost.

Although the problem-solving method is no guarantee of success, experience has indicated that an orderly approach will yield the highest probability of success. Problem solving concentration on improvements rather than control.

#### **Kaizen**

Kaizen is a Japanese word for the philosophy that defines management's role in continuously encouraging and implementing small improvements involving everyone. It is the process of continuous improvement in small increments that make the process more efficient, effective, under control and adaptable. It focuses on simplification by breaking down complex processes into their sub processes and then improving them.

The Kaizen improvement focuses on the use of :

1. Value-added and non-value added work activities.
2. Muda, which refers to the seven classes of waste.
3. Principles of motion study.
4. Principles of materials handling.
5. Documentation of standard operating procedures.
6. The five S's for work place organization which are five Japanese words that mean proper arrangement (seiko)
 

Order liners	(seiton)
Personal cleanliness	(seiketso)
Clean up	(seiso)
Discipline	(shit-suke)
7. Visual management by means of visual displays.
8. Just-in-time principles to produce only the units in the right quantities, at the right time and with the right resources.

9. Poka-Yoke to prevent or detect errors.
10. Team dynamics. Which includes problem solving, communication skills and conflict resolution.

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# 5s

*5s is the name of a workplace organization method that uses a list of five words: seiri, seiton, seiso, seiketsu, and shitsuke. Translated into English, they all start with the letter "S". This list of 5s describes how to organize a work space for efficiency and effectiveness by identifying and storing the items used, maintaining the area and items, and sustaining the new order. The decision-making process usually comes from a dialogue about standardization, which builds understanding among employees of how they should do the work.*

*There are five primary 5S phases: They are known as Sort, Stabilizing, Shine, Standardize and Sustain.*

## **1. Sorting**

*Eliminate all unnecessary tools, parts. Go through all tools, materials, and so forth in the plant and work area. Keep only essential items and eliminate what is not required, prioritizing things per requirements and keeping them in easily-accessible places. Everything else is stored or discarded.*

## **2. Straightening or Stabilizing**

*Arrange the work, workers, equipment, parts, and instructions in such a way that the work flows free of waste through the value added tasks with a division of labour necessary to meet demand.*

## **3. Systematic Cleaning**

*Clean the workspace and all equipment, and keep it clean, tidy and organized. At the end of each shift, clean the work area and be sure everything is restored to its place. This step ensures that the workstation is ready for the next user and that order is sustained.*

## **4. Standardize**

*Ensure uniform procedures and setups throughout the operation to promote interchangeability.*

## **5. Sustain**

*Ensure disciplined adherence to rules and procedures to prevent backsliding.*

# Kaizen

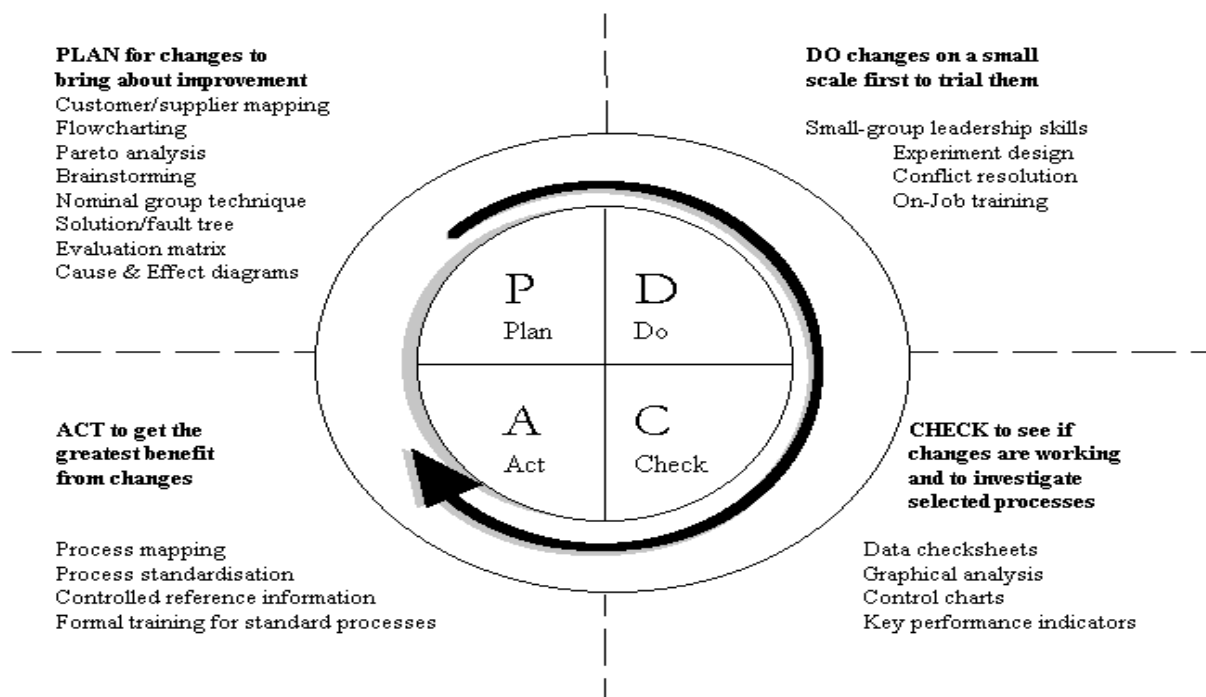
*Kaizen is a Japanese word which means good change for "improvement" or "change for the best", refers to philosophy or practices that focus upon continuous improvement of processes in manufacturing, engineering, and business management. It has been applied in healthcare, government, banking, and other industries. Kaizen refers to activities that continually improve all functions, and involves all employees. It also applies to processes, such as purchasing and logistics that cross organizational boundaries into the supply chain. By improving standardized activities and processes, kaizen aims to eliminate waste. Kaizen was first implemented in several Japanese businesses after the Second World War. It has since spread throughout the world. And is now being implemented in environments outside of business and productivity.*

*The Toyota Productive System is known for kaizen, where all line personnel are expected to stop their moving production line in case of any abnormality and, along with their supervisor, suggest an improvement to resolve the abnormality which may initiate a kaizen.*

*The cycle of kaizen activity can be defined as:*

- *Standardize an operation and activities.*
- *Measure the operation (find cycle time and amount of in-process inventory)*
- *Gauge measurements against requirements*
- *Innovate to meet requirements and increase productivity*
- *Standardize the new, improved operations*
- *Continue cycle ad infinitum*

*This is also known as PDCA cycle.*



*Draw picture of PDCA cycle.*



# Check Sheet

**Definition:** A simple data collection form consisting of multiple categories with definitions. Data are entered on the form with a simple tally mark each time one of the categories occurs.

**Purpose:** To facilitate the collection and analysis of data.

A check sheet is a simple means of data collection. The most straightforward check sheet is simply to make a list of items that you expect will appear in a process and to mark a check beside each item when it does appear. This type of data collection can be used for almost anything, from checking off the occurrence of particular types of defects to the counting of expected items (e.g., the number of times the telephone rings before being answered).

## How to Construct:

1. Clearly define the objective of the data collection.
2. Determine other information about the source of the data that should be recorded, such as shift, date, or machine.
3. Determine and define all categories of data to be collected.
4. Determine the time period for data collection and who will collect the data.
5. Determine how instructions will be given to those involved in data collection.
6. Design a check sheet by listing categories to be counted.
7. Pilot the check sheet to determine ease of use and reliability of results.
8. Modify the check sheet based on results of the pilot.

## Tips:

- Use Ishikawa diagrams or Brainstorming to determine categories to be used on the check sheet.
- Construct an operational definition of each category to ensure data collected is consistent.
- Make check sheet as clear and easy to use as possible.
- Spend adequate time explaining the objective of the data collection to those involved in recording the data to ensure the data will be reliable.◆
- Data collected in this format facilitates easy Pareto analysis.

# Beginner's Guide: The 7 Basic Quality Tools

## Tool #6 - The Xbar and R Control Chart

### The Control Chart Defined

Thus far in our training, we have learned that Histograms and Check sheets consolidate the data collected, to show the overall picture, while the Pareto diagram is used to indicate problem areas. However, for production purposes, we want to know more about the nature of changes that take place over a specified period of time, or as they occur in "real time".

Control charts are generally used in a production or manufacturing environment and are used to control, monitor and IMPROVE a process. Common causes are always present and generally attributed to machines, material and time vs. temperature. This normally takes a minor adjustment to the process to make the correction and return the process to a normal output. HOWEVER, when making a change to the process, it should always be a MINOR change. If a plot is observed that shows a slight deviation trend upward or downward, the "tweaking" adjustment should be a slight change, and then another observation should be made. Too often people will over-correct by making too big of an adjustment which then causes the process to dramatically shift in the other direction. For that reason, all changes to the process should be SLIGHT and GRADUAL!

A control chart is a graph or chart with limit lines, called control lines. There are basically three kinds of control lines:

- the upper control limit (UCL),
- the central line (actual nominal size of product),
- the lower control limit (LCL).

The purpose of drawing a control chart is to detect any changes in the process that would be evident by any abnormal points listed on the graph from the data collected. If these points are plotted in "real time", the operator will immediately see that the point is exceeding one of the control limits, or is heading in that direction, and can make an immediate adjustment. The operator should also record on the chart the cause of the drift, and what was done to correct the problem bringing the process back into a "state of control".

The method in which data is collected to be charted is as follows: A sampling plan is devised to measure parts and then to chart that measurement at a specified interval. The time interval and method of collection will vary. For our example, we will say that we collect data five times a day at specified time intervals. In making the control chart, the daily data is averaged out in order to obtain an average value for that day. Each of these values then becomes a point on the control chart that then represents the characteristics of that given day. To explain further, the five measurements made in one day constitute one subgroup, or one plot point. In some manufacturing firms, measurements are taken every 15 minutes, and the four plots (a subgroup) are totaled and then an average value is calculated. This value then equals one plot for the hour, and that plot is placed on the chart; thus, one plot point on the chart every hour of the working day.

It is when these plot points should fall outside the UCL or LCL, that some form of change must occur on the assembly or manufacturing line. Further, the cause needs to be investigated and have proper action taken to prevent it from happening again.....called preventative action, and continuous improvement in the Quality world. The use of control charts is called "process control." In reality, however, a trend will develop that indicates the process is leading away from the center line, and corrective action is usually taken prior to a point exceeding one of the control limits.

There are two main types of Control Charts. Certain data are based upon measurements, such as the measurement of unit parts. These are known as "indiscrete values" or "continuous data". Other types of data are based on counting, such as the number of defective articles or the number of defects. These are known as "discrete values" or "enumerated data".

## The Xbar & R Control Chart

An Xbar & R Control Chart is one that shows both the mean value ( X ), and the range ( R ). The Xbar portion of the chart mainly shows any changes in the mean value of the process, while the R portion shows any changes in the dispersion of the process. This chart is

particularly useful in that it shows changes in mean value and dispersion of the process at the same time, making it a very effective method for checking abnormalities within the process; and if charted while in progress, also points out a problem in the production flow in real time mode.

### Steps In Making the Xbar and R Chart

- **STEP #1 - Collect the data.** It is best to have at least 100 samples.
- **STEP #2 - Divide the data into subgroups,** it is recommended the subgroups be of 4 or 5 data points each. The number of samples is represented by the letter " n " and the number of subgroups is represented by the letter " k ". The data should be divided into subgroups in keeping with the following conditions:
  1. The data obtained should be from the same grouping of products produced.
  2. A sub group should not include data from a different lot or different process.
- **STEP #3 - Record the data on a data sheet.** Design the sheet so that it is easy to compute the values of X bar and R for each sub group (see the page in the class example).
- **STEP #4 - Find the mean value (Xbar).** Use the following formula for each subgroup:

$$\bar{X} = \frac{X1 + X2 + X3 + X4 + X5}{N} = \frac{65.0}{5} = 13.0$$

- **STEP #5 - Find the range, R.** Use the following formula for each subgroup.  
 $R = X \text{ (largest value)} - X \text{ (smallest value)}$  Example  $14.0 - 12.1 = 1.9$

### CLASS EXERCISE:

It is now time for you to practice some of your learning. I have completed many of the Xbar and R values for you, however, you really should perform a few calculations to gain the experience. Using the attached Exercise Sheet, calculate the remaining Xbar and R values.

[Click Here for the Excel Spreadsheet Version](#)

[Click Here for the Printable PDF Version](#)

- **STEP #6 - Find the overall mean, or X double bar  $\bar{\bar{X}}$ .**  
 Total the mean values of Xbar, for each subgroup and divide by the number of subgroups (k).

$$\bar{\bar{X}} = \frac{13.0 + 12.94 + 12.90 \dots + 12.72}{25} = \frac{323.50}{25} = 12.94$$

- **STEP #7 - Compute the average value of the range (R).** Total R for all the groups and divide by the number of subgroups (k).

$$\bar{R} = \frac{R1 + R2 + R3 \dots Rk}{k}$$

$$\bar{R} = \frac{1.9 + 1.3 + 1.1 \dots + 1.1}{25} = \frac{33.8}{25} = 1.35$$

**CLASS EXERCISE PART 2:**

On the same Work Sheet that you just computed the X double bar figures, now compute the R bar explained above.

- **STEP #8 - Compute the Control Limit Lines.** Use the following formulas for Xbar and R Control Charts. The coefficients for calculating the control lines are A2, D4, and D3 are located on the bottom of the Work Sheet you are presently using, and presented here:

<i>n</i>	<i>A2</i>	<i>D4</i>	<i>D3</i>
2	1.88	3.267	---
3	1.023	2.575	---
4	0.729	2.282	---
5	0.577	2.115	---
6	0.483	2.004	---
7	0.419	1.924	0.076
8	0.373	1.864	0.136
9	0.337	1.816	0.184
10	0.308	1.777	0.223

**Xbar Control Chart:**

Central Line (CL) = X double bar figure you calculated.

Upper Control Limit (UCL) = X double bar + A2 \* R bar.

Lower Control Limit (LCL) = X double bar - A2 \* R bar.

**R Control Chart:**

Central Line (CL) = R bar figure you calculated.

Upper Control Limit (UCL) = D4 \* R bar.

Lower Control Limit (LCL) = D3 \* R bar.

**For our Class Exercise, the details are as follows:**

X Control Chart CL = X double bar = 12.94

- UCL = 12.94 + .577 \* 1.35 = 13.719 Note that we are using 5 subgroups, so on the chart n = 5, and under the A2 column, 5 = 0.577. 1.35 is the figure you calculated for R bar.
- LCL = 12.94 - .577 \* 1.35 = 12.161

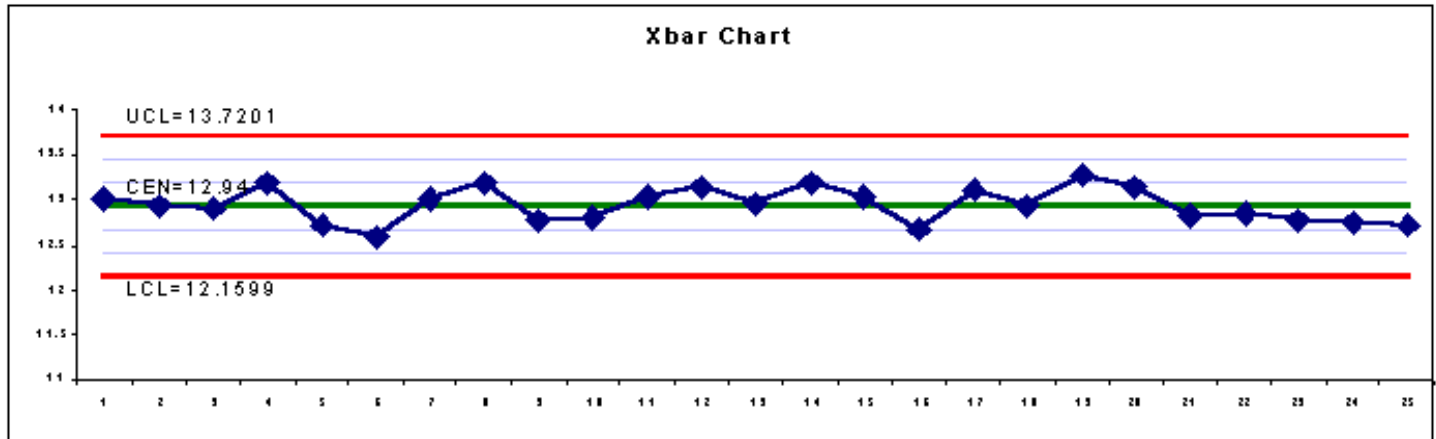
R Control Chart CL = R bar = 1.35

- UCL = 2.115 \* 1.35 = 2.86 Note that we are using 5 subgroups, so on the chart n = 5, and under the D4 column, 5 = 2.115.
- LCL = Since our subgroups equal 5, if you look under the D3 column, there is no calculation coefficient to apply, thus there is no LCL.

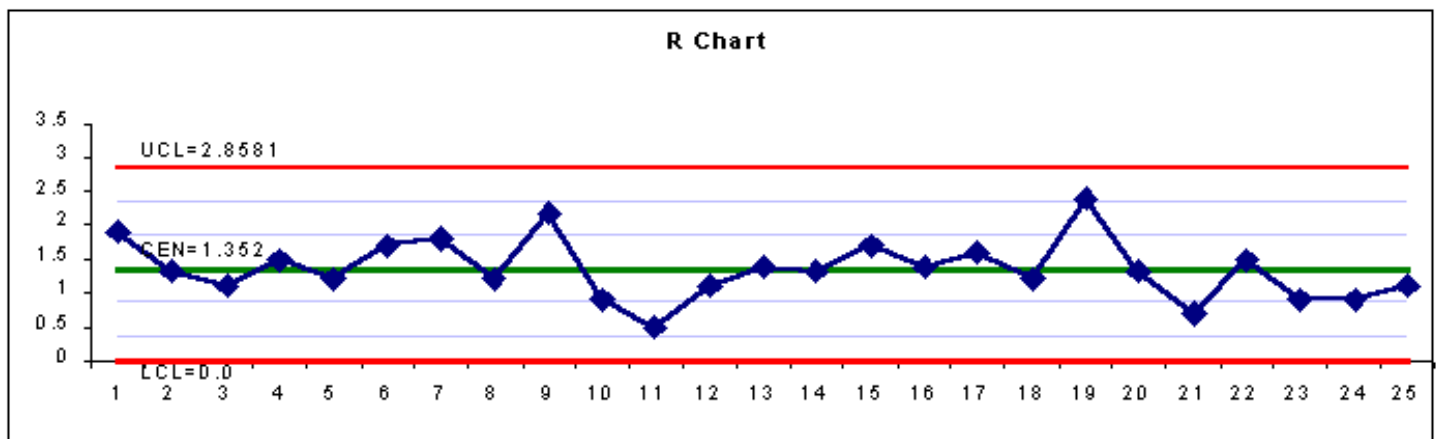
- **STEP #9 - Construct the Control Chart.** Using graph paper or Control Chart paper, set the index so that the upper and lower

control limits will be separated by 20 to 30 mm (units). Draw in the Control lines CL, UCL and LCL, and label them with their appropriate numerical values. It is recommended that you use a blue or black line for the CL, and a red line for the UCL and LCL. The central line is a solid line. The Upper and Lower control limits are usually drawn as broken lines.

- STEP #10 - Plot the Xbar and R values as computed for each subgroup. For the Xbar values, use a dot (.), and for the R values, use an (x). Circle any points that lie outside the control limit lines so that you can distinguish them from the others. The plotted points should be about 2 to 5 mm apart. Below is what our Xbar chart looks like when plotted.



Below is what our Rbar chart looks like when plotted.

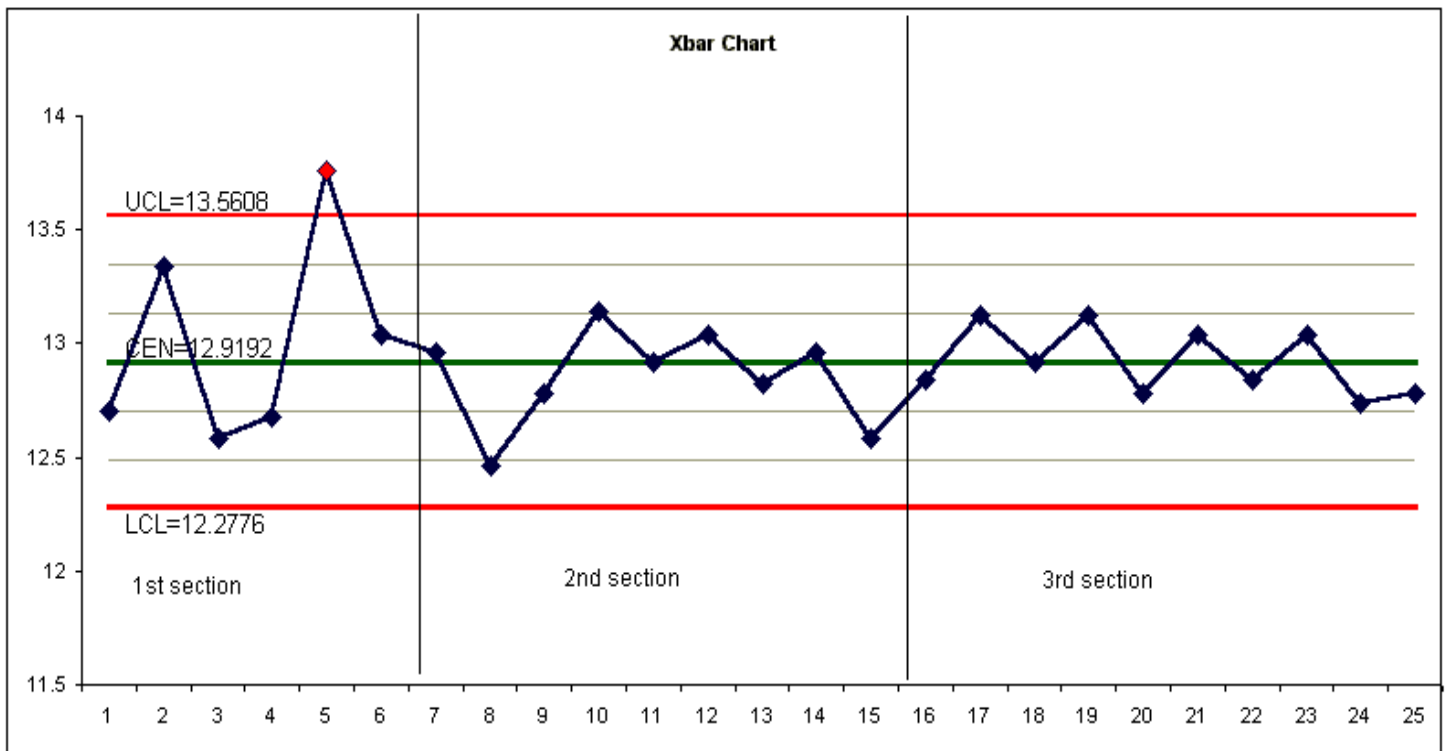


- STEP #11 - Write in the necessary information. On the top center of the control charts write the Xbar and R chart, and the R Chart so that you (and others) will know which chart is which. On the upper left hand corner of the Xbar control chart, write the n value to indicate the subgroup size; in this case n = 5.

## ANALYSIS OF THE CONTROL CHART

Now that we know how to make a control chart, it is even more important to understand how to interpret them and realize when there is a problem. All processes have some kind of variation, and this process variation can be partitioned into two main components. First, there is natural process variation, frequently called "common cause" or system variation. These are common variations caused by machines, material and the natural flow of the process. Secondly is special cause variation, generally caused by some problem or extraordinary occurrence in the system. It is our job to work at trying to eliminate or minimize both of these types of variation. Below is an example of a few different process variations, and how to recognize a potential problem.





In the above chart, there are three divided sections. The first section is termed "out of statistical control" for several reasons. Notice the inconsistent plot points, and that one point is outside of the control limits. This means that a source of special cause variation is present, it needs to be analyzed and resolved. Having a point outside the control limits is usually the most easily detectable condition. There is almost always an associated cause that can be easily traced to some malfunction in the process.

In the second section, even though the process is now in control, it is not really a smooth flowing process. All the points lie within the control limits, and thus exhibits only common cause variations.

In the third section, you will notice that the trending is more predictable and smoother flowing. It is in this section that there is evidence of process improvement and the variation has been reduced.

Therefore, to summarize, eliminating special cause variation keeps the process in control; process improvement reduces the process variation, and moves the control limits in toward the centerline of the process. At the beginning of this process run, it was in need of adjustment as the product output was sporadic. An adjustment was made, and while the plotted points were now within the boundaries, it is still not centered around the process specification. Finally, the process was tweaked a little more and in the third section, the process seems to center around the CL.

There are a few more terms listed below that you need to become familiar with when analyzing a Xbar Chart and the process:

**RUN** - When several plotted points line up consecutively on one side of a Central Line (CL), whether it is located above or below the CL, it is called a "run". If there are 7 points in a row on one side of the CL, there is an abnormality in the process and it requires an adjustment.

**TREND** - If there is a continued rise or fall in a series of points (like an upward or downward slant), it is considered a "trend" and usually indicates a process is drifting out of control. This usually requires a machine adjustment.

**PERIODICITY** - If the plotted points show the same pattern of change over equal intervals, it is called "periodicity". It looks much like a uniform roller coaster of the same size ups and downs around the centerline. This process should be watched closely as something is causing a defined uniform drift to both sides of the centerline.

**HUGGING** - When the points on the control chart seem to stick close to the center line or to a control limit line, it is called "hugging of the control line". This usually indicates that a different type of data, or data from different factors (or lines) have been mixed into the sub groupings. To determine if you are experiencing "hugging" of the control line, perform the following exercise. Draw a line equal distance between the centerline and the upper control limit. Then draw another line equal distance between the center line and the lower control limit. If the points remain inside of these new lines, there is an abnormality, and the process needs closer analysis.

## FINAL CLASS EXERCISE

Now it is time for the final test to see if you can make a Control Chart. Below is link for a completely filled out data sheet, and a blank variable control chart form. Your challenge is to calculate the subgroups Xbar and Rbar numbers; calculate the CL, UCL and LCL for the data and the Range Chart, and place those limit lines and numbers on the chart. Last, of course, plot the points and indicate if there are any abnormalities observed in the process. Below your forms to work on, you will also find the completed results so you can check your work. Good Luck!

**The Blank Variable Control Chart is available in two formats:**

For Microsoft Word Format [CLICK THIS LINK](#)

For Adobe Acrobat Format (.pdf) [CLICK THIS LINK](#)

**Your Completed Data Sheet for this Exercise is available in two formats:**

For Microsoft Excel Format [CHOOSE THIS LINK](#)

For Adobe Acrobat Format (.pdf) [CHOOSE THIS LINK](#)

**FINAL PRODUCT COMPARISON:** Your Final Xbar and R Chart should look [THIS CHART](#).

[Menu](#) | [Check Sheet](#) | [Pareto Diagram](#) | [Histogram](#) | [Cause-and-Effect](#)  
[Scatter Graph](#) | [Control Charts](#) | [Np Control Charts](#)