Module - 4

Continuous Process Improvement

Continuous process improvement is designed to utilize the resources of the organization to achieve a quality-driven culture.

Improvement is made by

- Viewing all work as process.
- All process effective, efficient and adaptable.
- Anticipating changing customer needs.
- Controlling in-process performance using measures such as scrap reduction, control charts
- Eliminating waste and re-work.
- Eliminating non-value added activities.
- Eliminating non-conformities.
- Using Benchmarking.
- Incorporating learned lessons into future activities.
- Using technical tools such as SPC, benchmarking, experimental design, QFD etc.

PROCESS

Process refers to business and production activities of an organization.

- **Processes for improvement-**eg. Design & Manufacturing, Marketing, Stores & Purchase,
- **Inputs of the Process-** Manpower, materials, money, data, etc.
- **Outputs-** Products, Services, data etc.
- Outputs need performance measures – main outcome being customer satisfaction.(**feedback** is used to improve the process)

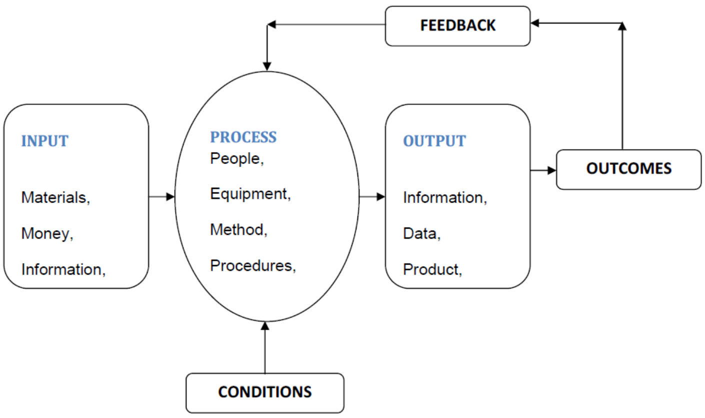


Fig. 4.1 Input / Output Process Model

There are five basic ways for improvement.

- Reduce resources.
- Reduce errors.
- Meet or exceed expectations of downstream customers.
- Make the process safer.
- Make the process more satisfying to the person doing it.

The Juran Trilogy Diagram

The Juran Trilogy consist three components - PLANNING, CONTROL AND IMPROVEMENT

Juran views quality as fitness for use.

Juran Trilogy is designed to reduce the cost of quality over time.

1. QUALITY PLANNING

1. Determine internal & external customers.
2. Their needs are discovered.
3. Develop product / service features.
4. Develop the processes able to produce the product / service features.
5. Transfer plans to operations.

2. QUALITY CONTROL

Control is used by operating forces to help meet the product, process and service requirements.

It consists of the following steps

1. Determine items to be controlled.
2. Set goals for the controls.
3. Measure actual performance.
4. Compare actual performance to goals.
5. Act on the difference.

3. QUALITY IMPROVEMENT

Aims to attain levels of performance that are higher than current levels.
It consists of the following steps

1. Establishment of quality council.
2. Identify the improvement projects.
3. Establish the project teams with a project leader.
4. Provide the team with the resources.

- Juran developed the quality trilogy-- quality planning, quality control and quality improvement.
- These three processes of the Juran trilogy are interrelated.

- The Juran trilogy diagram is a graph with time on the horizontal axis and cost of poor quality on the vertical axis (refer to figure 2).
- The initial activity is quality planning. The planners identify the customers and their needs. Then, they develop product and process designs to respond to those needs. Finally, the planners turn the plans over to the operating forces, "You run the process, produce the product features and meet the customers' needs."

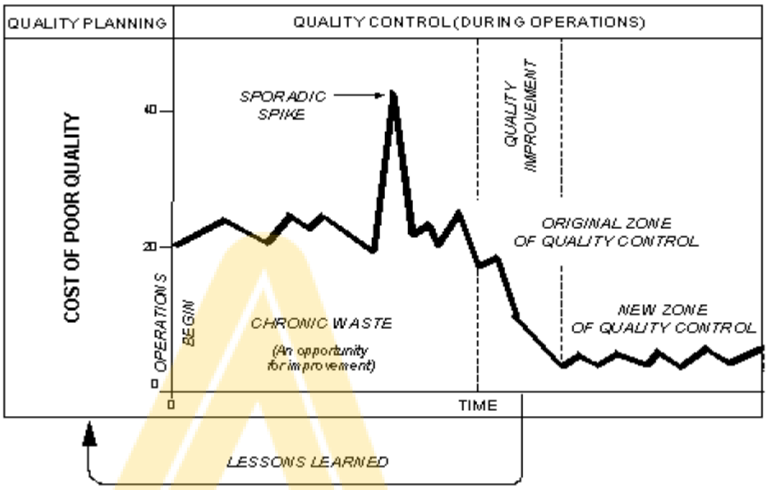


Fig.4. 2-- The Juran trilogy diagram

Chronic and Sporadic

- As operations proceed, it soon emerges that the process is unable to produce 100 percent good work. Fig. 2 shows that over 20 percent of the work usually has to be redone due to quality deficiencies. This waste is chronic as it goes on and on.
- The reason of this chronic waste is the wrong planning of operating process. What they can do is to carry out quality control, i.e. to prevent things from getting worse.
- Fig. 2 also shows a sudden sporadic spike that has raised the defect level to over 40 percent. This spike might be resulted from some unplanned event such as a power failure, process breakdown, or human error.
- As a part of their job of quality control, the operating forces converge on thescene and take action to restore the status quo. This is often called "corrective action,"
- "Troubleshooting," "putting out the fire" and so on. The end result is to restore the error level back to the planned chronic level of about 20 percent.
- The figure also shows that, in due course, the chronic waste was driven down to a level far below the original level. This gain came from the third process in the trilogy--quality improvement.

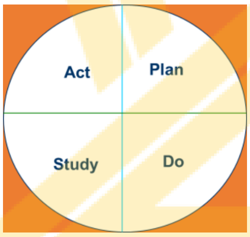
- In effect, it was seen that the chronic waste was an opportunity for improvement and steps were taken to make that improvement.

The Trilogy Diagram and Product Deficiencies

The trilogy diagram relates to product deficiencies. The vertical scale exhibits units of measure such as cost of poor quality, error rate, percent defective, service rate and so on. On this same scale, perfection is at zero and what goes up is bad. The results of reducing deficiencies are reduction of the cost of poor quality, meeting more delivery promises, reduction of customer dissatisfaction and so on.

PDCA Cycle

It is an extremely practical, common sense based approach that is easy to understand.It can be used to test ideas for improvement quickly and easily based on existing ideas,research, feedback, theory, review, audit, etc.It encourages starting with small changes, which can build into large improvements in theservice through successive quick cycles of change.



Phases Description

1. Plan

- Define the problem
- Analyse the causes and draft an action plan for solving the problem.
- Determine the quality objectives and the critical factors.
- Define the performance indicators.
- Collect and analyse the necessary process data.
- Generate possible solutions
- Select the most feasible solution; and work it out.

2. Do

- First, implement the plan on a limited scale or conduct an experiment to test the proposed improvement. Collection data is hereby essential.

- Train all involved employees in the use of quality improvement methods and techniques.
- Describe the process which is considered for improvement and form project teams to lead the process.

3. Check

- Evaluate the trial project with the performance indicators.
- Verify whether the improvement has been successful or not.

4. Act

- Act to implement proven improvements. The choices are: introduce the plan, adjust or reject it.
- The improvements are documented in standard procedures so all employees are well informed on how to handle in future.
- Usually, the cycle will be repeated under the different circumstances and conditions to test how consistent the results are.

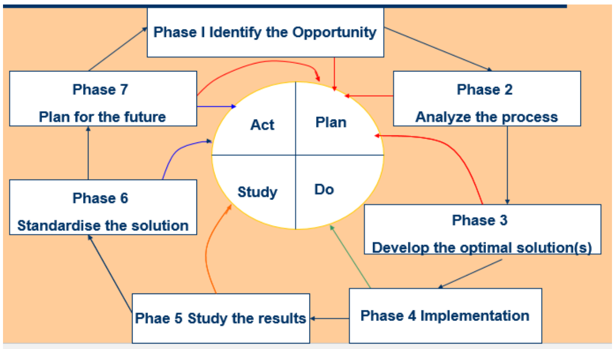
PROBLEM SOLVING METHOD

1. Identify the Opportunity

- Identify the Problem
- Pareto analysis of external alarm signals such as field analysis, such as field failures, complaints, returns etc.
- Pareto analysis of internal alarm signals such as scrap, rework, sorting etc.
- Proposals from key insiders such as managers, supervisors, union leaders etc.
- Proposals from suggestion schemes.
- Field study of user's needs.
- Comments of key people outside the organization.
- Customer surveys.
- Employee surveys.
- Brainstorming by work groups.

Form the Team

- Team should be selected.
- Goals and milestones are established.
- Define the Scope.



2. Analyze the Current Process

The objective is to understand the process and how it is currently performed.

Step 1: The team to develop a process flow diagram.

Step 2: The target performance measures are defined.

Step 3: Collection of all available data and information.

Common items of data and information are

1. Customer information 2. Design information 3. Process information 4. Statistical information 5. Quality information 6. Supplier information

3. Develop the Optimal Solution(S)

This phase has the objective of establishing potential and feasible solutions and recommending the best solution to improve the process.Creativity plays the major role, and brainstorming is the principal technique.

There are three types of creativity:

- Create new processes
- Combine different processes
- Modify the existing process

4. Implement Changes

This phase has the objective of preparing the implementation plan, obtaining approval and implementing the process improvements.

- Approval of the quality council.
- Obtain the advice and consent of departments, functional areas, teams, individuals etc.
- Monitor the activity.

5. **Study the Results**

This phase has the objective of monitoring and evaluating the change by tracking and studying the effectiveness of the improvement efforts.

6. Standardize the Solution

- Institutionalize by positive control of the process.
- The quality peripherals – the system, environment and supervision must be certified.
- Operators must be certified.

7. Plan for the Future

- The objective is to achieve improved level of process performance.
- Regularly conduct reviews of progress by the quality council.
- Establish the systems to identify area for future improvements.
- Track performance with respective internal & external customers.
- TQM tools and techniques are used to improve quality, delivery and cost.

Benefits of the PDSA Cycle

The benefits of the PDSA cycle can be experienced in the following areas:

- Daily routine management – for the individual and / or the team.
- Problem-solving process.
- Project management
- Continuous development
- Vendor development
- Human resources development
- New product development
- Process trials

Introduction to Kaizen

- Kaizen- defines the management's role in continuously encouraging and implementing small improvements in the individual & organization.
- Break the complex process into sub-processes and then improve the sub-processes.
- Continuous improvements in small increments make the process more efficient, controllable and adaptable.
- Does not rely on more expense, or sophisticated equipment and techniques.

The kaizen improvement focus on the following factors.

- Value and non-value added work activities
- Muda-which refers to seven classes of waste such as over production, delay, transportation, processing, inventory, motion, and defective components.
- Principles of time and motion study
- Principles of materials handling and use of one-piece flow

- Documentation of standard operating procedures
- The 5S's
- Visual displays for communicating to factory personnel
- JIT- to produce right quantities at right time and with right resources
- Poka-yoke to prevent or detect errors
- Team dynamics – problem solving, communication, conflict resolution.

One of the key aspects of Kaizen is that it is an on-going, never-ending improvement process.

- ➢ The concept of continuous improvement is applied in all directions. Industrial processes and working methods can be improved.
- ➢ Quality defects can be eliminated and waste can be reduced.
- ➢ Customer service can be made better. The work environment can be improved.

What is 5s and why do we want to do it?

5S represents five disciplines for maintaining a visual workplace. These are foundational to Kaizen and a manufacturing strategy based "Lean Manufacturing" concepts. 5S is the starting point for improvement activities that ensure our company's survival. The five disciplines are:

1. Sort

Remove all items from the workplace that are not needed for current operations. Leave only the bare essentials.

2. Set in Order

Arrange needed items so that they are easy to find, use and put away.

3. Shine

Sweeping, wiping-off equipment, painting and assuring everything stays clean.

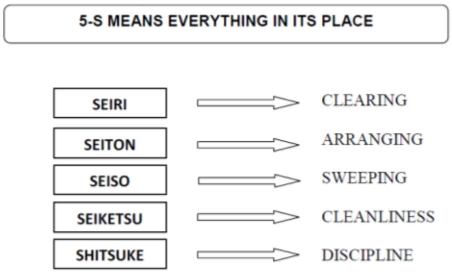
4. Standardize

Method to maintain the first three disciplines (sort, set-in-order, and shine)

5. Sustain

A top-down support of the ongoing 5S process should:

- Create the conditions to support 5S
- Allocate time
- Create awareness
- Provide a structure
- Show support
- Offer rewards and recognition
- Encourage training/participation



Kaizen and Innovation

Innovation means to make improvements by investing a large sum of money in equipment, or introducing a latest technology to make a big change. While Kaizen subscribes to a gradual improvement, innovation subscribes to a big revolutionary change. In today's stagnant business environment, Kaizen may be a more desirable alternative than innovation.

	Kaizen	**Innovation**
1. Effect	Long-term and long-lasting but un-dramatic	Short-term but dramatic
2. Pace	Small steps	Big steps
3. Timeframe	Continuous and incremental	Intermittent and non-incremental
4. Change	Gradual and constant	Abrupt and volatile
5. Involvement	Everybody	Select few "champions"
6. Approach	Collectivism, group efforts, systems approach	Rugged individualism, individual ideas and efforts
7. Mode	Maintenance and improvement	Scrap and rebuild
8. Spark	Conventional know-how and state of the art	Technological breakthroughs, new inventions, new theories
9. Practical requirements	Requires little investment but great effort to maintain it	Requires large investment but little effort to maintain it
10. Effort orientation	People	Technology
11. Evaluation criteria	Process and efforts for better results	Results for profits
12. Advantage	Works well in slow-growth economy	Better suited to fast-growth economy

REENGINEERING

Reengineering is the systematic transformation of an existing system into a new form to realize quality improvements in operation, system capability, functionality, performance, or evaluability at a lower cost, schedule, or risk to the customer."

Why Reengineering?

- Evolutionary reasons
- Current system lacks desired functionality (new technology)

- Time and Money savings
- Less cost than a new system
- Quicker to Implement
- Increased Developer Productivity

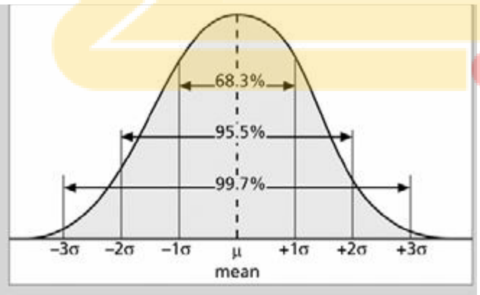
SIX SIGMA

Sigma

The term sigma means standard deviation. Standard deviation measures how much variationexists in a distribution of data. It is a key factor in determining the acceptable number ofdefective units found in a population. Six sigma projects strive for no more than 3.4 defects permillion opportunities, yet this number is confusing to many statisticians.

Standard Deviation

Small standard deviation means that data cluster closely around the middle of a distribution andthere is little variability among the data. Normal distribution is the bell-shaped curve that issymmetrical about the mean or average value of a population.



The normal curve

Definition

Six sigma at many organizations simply means a measure of quality that strives for nearperfection. Six sigma is a disciplined, data-driven approach and methodology for eliminatingdefects (driving toward six standard deviations between the mean and the nearest specificationlimit) in any process-- from manufacturing to transactional and from product to service.

- **Six sigma** stands for six standard deviation from mean (sigma is the Greek letter used to represent standard deviation in statistics).
- Six sigma, similar to Zero Defect (ZD), is a philosophical benchmark or standard of excellence proposed by Philip Crosby.
- Six sigma methodology provides the techniques and tools to improve the capability and reduce the defects in any process.
- It was started by Motorola in 1987, in its manufacturing division.
- Six sigma strives for perfection. **It allows for only 3.4 defects per million opportunities (or99.999666 percent accuracy).** Here a defect can be anything from a faulty party to an incorrect customer bill.
- Six sigma improves the process performance, decrease variation and maintains **consistent quality** of the process output. This leads to defect reduction and improvements in profits,product quality and customer satisfaction.
- Six sigma incorporates the basic principles and techniques used in business, statistics and engineering.
- **The objective of six sigma principle** is to achieve zero defects products/process. It allows 3.4 defects per million opportunities.
- Unlike the statistical term, "sigma" is a measure of conformance to specification. Table 12.1 shows examples.

Six Sigma and Defective Units

Table 12.1-- Data for the short-term process output

Specification Range (in +/- Sigmas)	Percent of Population Within Range	Defective Units Per Billion
1	68.27	317,300,000
2	95.45	45,400,000
3	99.73	2,700,000
4	99.9937	63,000
5	99.999943	57
6	99.9999998	2

As non-conforming rate decreases, "sigma" rating increases. The sigma rating is based on the distribution of a process output as related to a customer requirement. Figure 12.2 shows the short-term process output (solid blue) which is centered in the specification. The short-term variability of the process output is such that the Upper Specification Limit (USL) and the Lower

Specification Limit (LSL) are both six standard deviations (called σ or sigma in statistical parlance) away from the center. Recognizing that most of the processes shift somewhat over a long period of time, an arbitrary change of plus or minus 1.5σ is expected to happen, leaving

4.5σ between the shifted average and the specification limit. This means that a process running at a six sigma level in the short term can tolerate a relatively large amount of drift and still makeonly 3.4 PPM nonconforming over the long term with the dashed blue line.

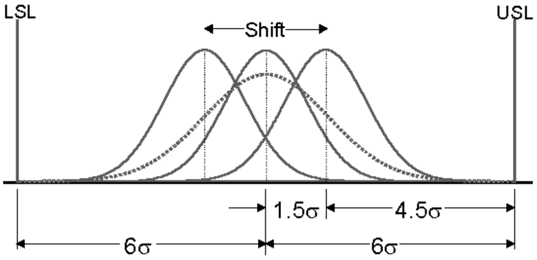


Figure 12.2-- Short-term process output

Phases of Six Sigma

There are six generic implementation phases for six sigma. These are as follows:

- Establish management commitment
- Business diagnostics
- Develop the management infrastructure
- Business process identification and metrics
- Project selection
- Deployment
- Training
- Project execution
- Review

DMAIC methodology provides a structured framework for solving business problems by assuring correct and effective process execution.

This methodology has 6 phases in which, in the case of Six Sigma, teams take total employee involvement approaches to complete the cycle of process management and use self-diagnosis skills to fulfil the goals of each phase.

DMAIC – It is used for improving existing processes/products.

DMADV – It is applied to a new processes/products.

Why is it important?

World-class companies typically operate at about four sigma or 99% perfection. To get to the six-sigma level means cutting down on huge costs and thereby wasted dollars. For example, if you were at four-sigma level, you would be producing products at the rate of 6,200 defectives for every million you produce vs. 3.4 defectives if you are at the six-sigma level. The popularity of six sigma is growing.

Each Six Sigma project carried out within an organization follows a defined sequence of steps and has quantified value targets, for example: reduce process cycle time, reduce pollution, reduce costs, increase customer satisfaction, and increase profits.

Some of the companies that have successfully implemented six sigma are as follows:

1. Motorola (1987) 2. Texas Instruments (1988) 3. IBM (1990)
4. GE (1995) 5.Whirlpool 6. Sony
7. Honda 8. Hitachi 9. Canon etc.

Recently, Ford, DuPont, Dow Chemical, Microsoft and American Express have started working on instituting six sigma processes.

Application of six sigma

Today six sigma can apply to many fields such as services, medical and insurance procedures, call centers etc.,

Pareto and Process Flow Diagram

4.1 Pareto Diagram

Alfredo Pareto (1848-1923) conducted extensive studies of distributions of wealth in Europe. He found that there were a few people with a lot of money and many people with little money. This unequal distribution of wealth became an integral part of economic theory. Dr. Joseph Juran recognized this concept as a universal truth that could be applied to many fields. He coined the phrases ―vital few‖ and ―useful many.‖

In restaurant quality problems, the activity could be customer complaints and the factor could be ―discourteous customer.‖ For a manufacturer, the activity could be product defect and a factor could be ―missing product.‖ Pareto concept, called the 80/20 rule, is that 80 percent of the activity is caused by 20 percent of factors. By concentrating on the 20 percent of the factors (the vital few), a manager can attack 80 percent of the quality problems.

Examples of the vital few are as follows:

- A few customers account for the majority of sales.
- A few processes account for the bulk of the scrap or rework cost.
- A few nonconformities account for the majority of customer complaints.
- A few suppliers account for the majority of rejected parts.
- A few problems account for the bulk of the process downtime.
- A few products account for the majority of the profit.
- A few items account for the bulk of the inventory cost.

Some Sample 80/20 Rule Applications

- 80% of process defects arise from 20% of the process issues.
- 20% of your sales force produces 80% of your company revenue.

- 80% of delays in schedule arise from 20% of the possible causes of the delays.
- 80% of customer complaints arise from 20% of your products or services.

The few vital factors can be identified with a Pareto chart or diagram, a bar chart on which the factors are plotted in decreasing order of frequency along the horizontal axis. The chart has two vertical axes, the one on the left showing frequency (as in a histogram) and the one on the right showing the cumulative percentage of frequency. The cumulative frequency curve identifies the few vital factors that warrant immediate managerial attention.

Construction

- Determine the categories and the units for comparison of the data, such as frequency, cost or time.
- Total the raw data in each category and then determine the grand total by adding the totals of each category.
- Reorder the categories from largest to smallest.
- Determine the cumulative percent of each category (i.e. the sum of each category plus all categories that precede it in the rank order, divided by the grand total and multiplied by 100).
- Draw and label the left-hand vertical axis with the unit of comparison, such as frequency, cost or time.
- Draw and label the horizontal axis with the categories. List from left to right in rank order.
- Draw and label the right-hand vertical axis from 0 to 100 percent. The 100 percent should line up with the grand total on the left hand vertical axis.
- Beginning with the largest category, draw in bars for each category representing the total for that category.
- Draw a line graph beginning at the right hand corner of the first bar to represent the cumulative percent for each category as measured on the right hand axis.
- Analyze the chart. Usually, the top 20% of the categories will comprise roughly 80% of the cumulative total.

Example-- Pareto Chart for a Restaurant

The manager of a neighbourhood restaurant is concerned about the smallest numbers of customers patronizing his eatery. The numbers of complaints have been rising of late. He would like some means of finding out what issues to address and of presenting the findings in a way his employees can understand them.

Solution

The manger surveyed his customers over several weeks and collected the following data:

Complaint	**Frequency**
Discourteous server	12
Slow service	42
Cold dinner	5
Cramped tables	20
Smoky air	10

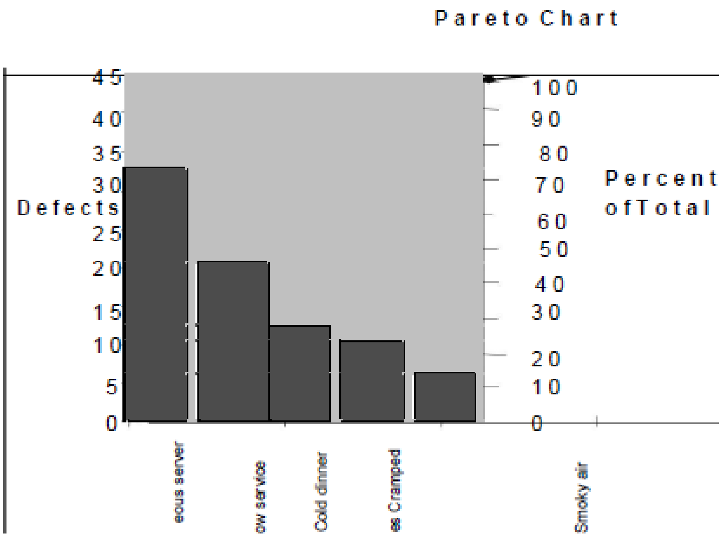


Figure 21.1– Pareto chart

Decision

It was clear to the manager and all employees which complaints, if rectified, would cover most of the quality problems in restaurant. First, slow service will be addressed by training the existing staff, adding another server and improving the food preparation process. Removing some decorative, but otherwise unnecessary, furniture from dining area and spacing the tables better will solve the problems with cramped tables. The Pareto chart shows that these two problems, if rectified, will account for almost 70 percent of the complaints.

Some possible uses could include the following:

Hotels-- Customer complaints at reception, noise levels in rooms, heating in rooms etc.

Accidents and injuries-- Fractures, eye and foreign bodies, muscle injuries, back injuries, burns, cuts, bruises etc.

4.2 Process Flow Diagram

Purpose

A flowchart is a pictorial representation of the steps in a given process. The steps are presented graphically in sequence so that team members can examine the order presented and come to a common understanding of how the process operates.

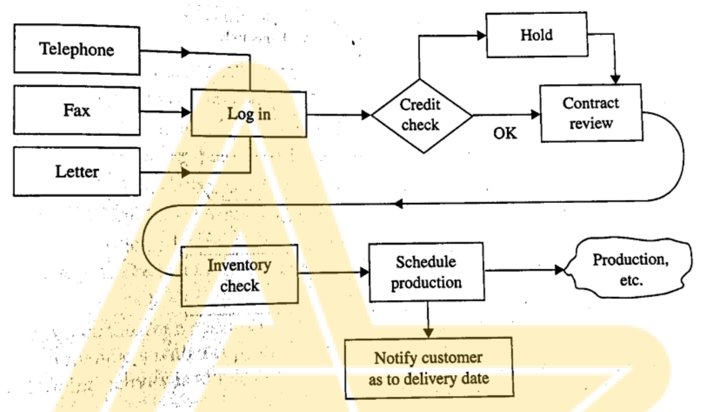
Flowcharts can be used to describe an existing process or to present a proposed change in the flow of a process. Flowcharts are the easiest way to "picture" a process, especially if it is very complex. Flowcharts should include every activity in the process. A flowchart should be the first step in identifying problems and targeting areas for improvement.

Steps in Flowcharting a Process

- Decide on the process of flowchart.
- Define the boundaries of the process-- the beginning and the end.
- Describe the beginning step of the process in an oval.

- Ask yourself what happens next?" and add the step to the flowchart as a rectangle. Continue mapping out the steps as rectangles connected by one-way arrows.
- When a decision point is reached, write the decision in the form of a question in a diamond and develop the "yes" and "no" paths. Each yes/no path should re-enter the process or exit somewhere.
- Repeat steps 4 and 5 until the last step in the process is reached.
- Describe the ending boundary/step in an oval.

When drawing a flowchart, constantly ask "what happens next," "is there a decision made at this point," "does this reflect reality," "who else knows this process" etc. When possible, do a walk-through of the process to see if any steps have been left out or extras added that should not be there. The key is not to draw a flowchart representing how the process is supposed to operate, but to determine how it actually does operate.



4.3 Check Sheets

The main purpose of check sheets is to ensure that operating personnel collects the data carefully accurately. Data should be collected in such a manner that it can be quickly and easily used and analyzed. The form of the check sheet is individualized for each situation and is designed by the project team. Figure below shows a check sheet for paint non-conformities for bicycles.

Figure belowshows a check sheet for temperature. The scale on the left represents midpoint and boundaries for each temperature range. Data for this type of check sheet is frequently recorded by placing an —X in the appropriate square. In this case, the time has been recorded in order to provide additional information for problem solving.

Whenever possible, check sheets are also designed to show location. For example the check sheet for bicycle paint non-conformities could show an outline of a bicycle with X's indicating the location of the non-conformities. Creativity plays a major role in the design of a check sheet. It should be user-friendly and whenever possible should include information on time and location.

CHECK SHEET

Product: Bicycle 32	Number inspected: 2217	
Nonconformity type	Check	Total
Blister	卌 卌 卌 卌 I	21
Light spray	卌 卌 卌 卌 卌 卌 卌 III	38
Drips	卌 卌 卌 卌 II	22
Overspray	卌 卌 I	11
Runs	卌 卌 卌 卌 卌 卌 卌 卌 卌 II	47
Others	卌	5
	Total	144
Number Nonconforming	卌 III	113

Check sheet for bicycle paint non-conformities

387.4 385 382.5								
382.4 380 377.5								
37 375 372.5	10.0							
372.4 370 367.5								
367.4 365 362.5	7.0	7.5	9.0					
362.4 360 357.5	8.0	8.5						
357.4 355 352.5	9.5							

Check sheet for temperature

4.4 Histogram

Histogram is used to display in bar graph format measurement data distributed by categories.

A histogram is used for the following:

Making decisions about a process, product or procedure that could be improved after examining the variation. For example, should the school invest in a computer-based tutoring program for low achieving students in Algebra after examining the grade distribution, are more shafts being produced out of specifications that are too big rather than too small?

Displaying easily the variation in the process. For example, which units are causing maximum difficulty for students, is the variation in a process due to parts that are too long or parts that are too short?

Steps in Constructing a Histogram

- Gather and tabulate data on a process, product or procedure. This could be time, weight, size, frequency of occurrences, test scores, GPA's, pass/fail rates, number of days to complete a cycle, diameter of shafts built etc.
- Calculate the range of the data by subtracting the smallest number in the data set from the largest. Call this value R.
- Decide about how many bars (or classes) you want to display in your eventual histogram. Call this number K. This number should never be less than four and seldom exceeds 12. With 100 numbers, K=7 generally works well. With 1000 pieces of data, K=11 works well.
- Determine the fixed width of each class by dividing the range, R by the number of classes K. This value should be rounded to a "nice" number, generally a number ending in a zero. For example, 11.3 would not be a "nice" number. 10 would be considered a "nice" number. Call this number i, for interval width. It is important to use "nice" numbers else the histogram created will have strange scales on the X-axis.
- Create a table of upper and lower class limits. Add the interval width (i) to the first "nice" number less than the lowest value in the data set to determine the upper limit of the first class. This first "nice" number becomes the lowest lower limit of the first class. The upper limit of the first class becomes the lower limit of the second class. Adding the internal width (i) to the lower limit of the second class, it determines the upper limit for the second class. Repeat this process until the largest upper limit exceeds the biggest piece of data. You should have approximately K classes or categories in total.
- Sort, organize or categorize the data in such a way that you can count or tabulate how many pieces of data fall into each of the classes or categories in your table above. These are the frequency counts and will be plotted on the Y-axis of the histogram.
- Create the framework for the horizontal and vertical axes of the histogram. On the horizontal axis, plot the lower and upper limits of each class determined above. The scale on the vertical axis should run from zero to the first "nice" number greater than the largest frequency count determined above.
- Plot the frequency data on the histogram framework by drawing vertical bars for each class. The height of each bar represents the number or frequency of values occurring between the lower and upper limits of that class.
- Interpret the histogram for skew and clustering problems

Example

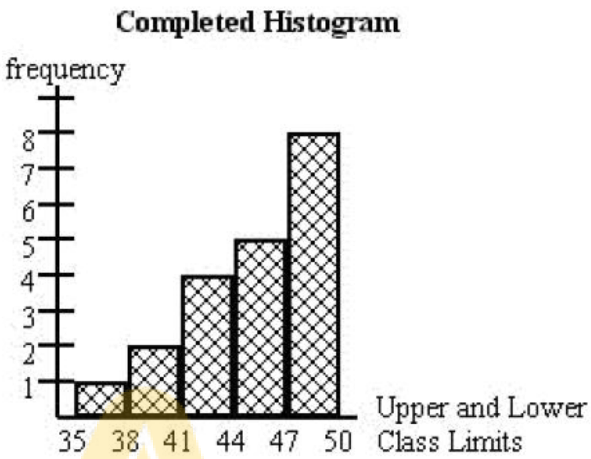
The data below are the spelling test scores for 20 students on a 50- word spelling test. The scores (number correct) are 48, 49, 50, 46, 47, 47, 35, 38, 40, 42, 45, 47, 48, 44, 43, 46, 45, 42, 43 and 47.

The largest number is 50 and the smallest is 35. Thus, the range, R = 15. We will use 5 classes, so K=5. The interval width i = R/K = 15/5 = 3.

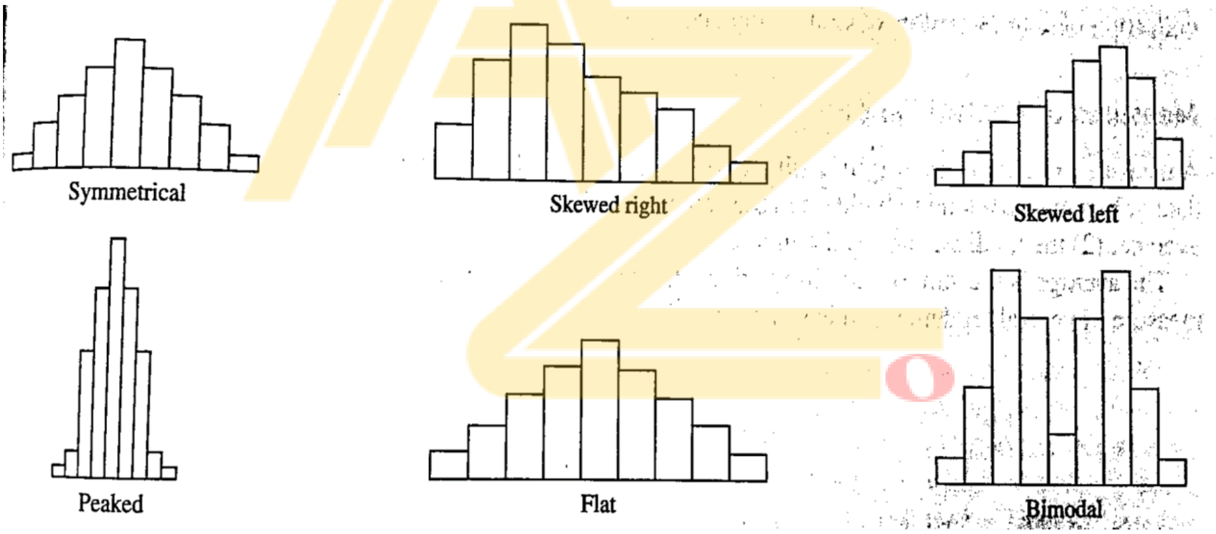
Then we will make our lowest lower limit, the lower limit for the first class 35. Thus, the first upper limit is 35+3 or 38. The second class will have a lower limit of 38 and an upper limit of 41. The completed table (with frequencies tabulated) will look like the following:

Class	Lower Limit	Upper Limit	Frequency
1	35	38	1

2	38	41	2
3	41	44	4
4	44	47	5
5	47	50	8



Examples of Typical Distributions



Limitations of Technique

Histograms are limited in their use due to the random order in which samples are taken and lack of information about the state of control of the process. Because samples are gathered without regard to order, the time-dependent or time-related trends in the process are not captured. So, what may appear to be the central tendency of the data may be deceiving. With respect to process statistical control, the histogram gives no indication whether the process was operating at its best when the data was collected. This lack of information on process control may lead to incorrect conclusions being drawn and, hence, inappropriate decisions being made. Still, with these considerations in mind, the histogram's simplicity of construction and ease of use make it an invaluable tool in the elementary stages of data analysis.

4.5 Control Charts

Introduction to Control Charts

Sources of Variation

As we know, no two products or services are exactly alike because the processes used to produce them contain many sources of variation, even if the processes are working as intended. For example, the diameter of two crankshafts may vary because of differences in tool wear, material hardness, operator skill, or temperature during the period in which they were produced. Similarly, time required to process two credit card applications varies because of the load on the credit card department, the financial background of the applicant and the skill and attributes of the employees. Nothing can be done to eliminate variation in process output completely, but management can investigate the causes of variation to minimize it.

Common Causes

There are two basic categories of variation in output:

Common Causes and Assignable Causes

Common causes of variation are purely random, unpredictable sources of variation that are unavoidable with the current process. For example, a machine that fills cereal boxes will not put exactly the same amount of cereal in each box. If you weighed a large number of boxes filled by the machine and plotted the results in a scatter diagram, the data would tend to form a pattern that can be described as a distribution. The mean, spread and the shape may characterize such a distribution.

1. Mean is the sum of the observations divided by the total number of observations:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

x_i = Observations of a quality characteristic (such as weight)
$\bar{x}$ = Mean
n = total no. of observations

Spread is the measure of the dispersion of observations about the mean. Two measures commonly used in practice are the range and the standard deviation. Range is the difference between the largest observation in a sample and the smallest. Standard deviation is the square root of the variance of distribution. An estimate of the population standard deviation based on sample is given by

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

x_i = Observations of a quality characteristic (such as weight)

$\bar{x}$ = Mean

n = total no. of observations

= Standard deviation of a sample.

Two common shapes of process distribution are symmetric and skewed. A Symmetric distribution has the same number of observations above and below the mean. A skewed distribution has preponderance of observations either the above or below the mean.

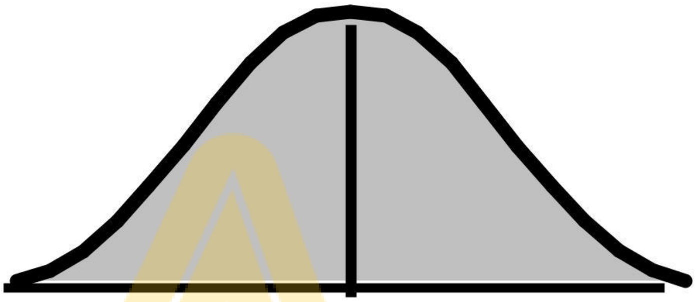


Figure- Distribution for the box-filling machine

If the process variability comes solely from causes of variation, a typical assumption is that distribution is symmetric, with most of observations near the center. Figure shows the distribution for the box-filling machine when only common causes of variation are present. The mean weight is 425 grams and the distribution is symmetric relative to mean.

Assignable Causes

The second category of variation, assignable causes of variation, also known as special causes, includes any variation causing factors that can be identified and eliminated. Assignable causes of variation include an employee needing training, or a machine needing repair. Let us return to the example of box filling machine.

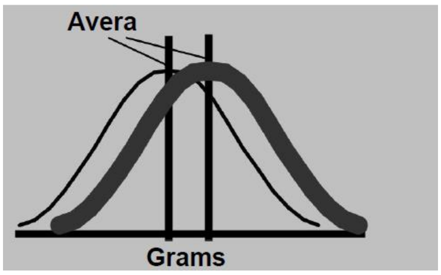


Figure (a) Location

Above figure shows how assignable causes can change the distribution of the output for the box-filling machine. The thin curve shows is the process distribution when only common causes of variation are present. The thick line curve depicts a change in the distribution because of assignable causes.

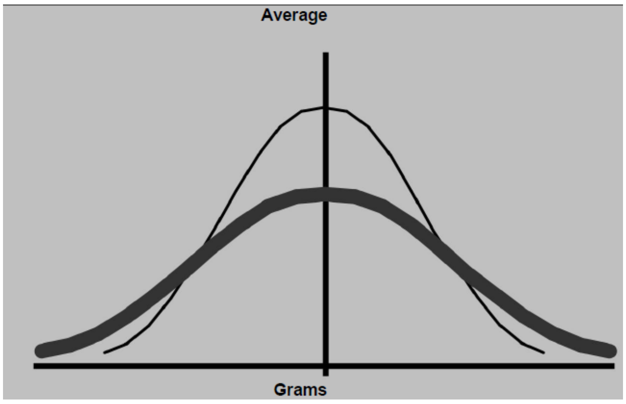


Figure (b). spread

In above figure (a), the thick curve indicates that the machine put more cereal than planned in all the boxes, thereby increasing the average weight of each box. In figure (b), an increase in the variability of the weight of cereal in each box affected the spread of distribution. Finally in figure (c), the thick line indicates that the machine produced lighter than heavier boxes. Such a distribution is skewed, i.e. it is no longer symmetric to the average value.

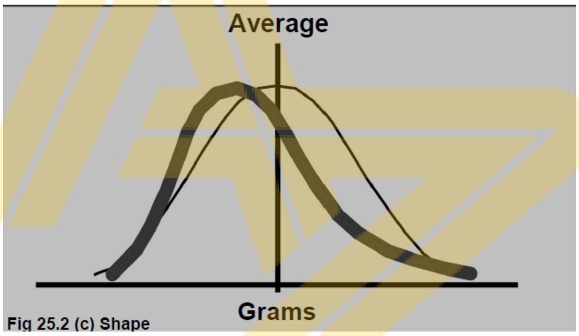


Figure (c) Shape

A process is said to be in statistical control when the location, spread or shape of its distribution does not change over time. After the process is in statistical control, managers use SPC procedures to detect the onset of assignable causes so that they can be eliminated.

Figure (a) shows the differences between a process that is in statistical control and the one that is not. In figure (a), the machine is generating different distributions of cereal box weight over time, indicating assignable causes that need to be eliminated. In figure (b), the distribution of weight is stable over time. Consequently, the process is in statistical control.