Chapter 2

Methods and Philosophy of Statistical Process Control

Basic SPC Tools

SPC can be applied to *any* process. Its seven major tools are

1. Histogram
2. Check sheet
3. Pareto chart
4. Cause-and-effect diagram
5. Defect concentration diagram
6. Scatter diagram
7. Control chart

Chance and Assignable Causes of Quality Variation

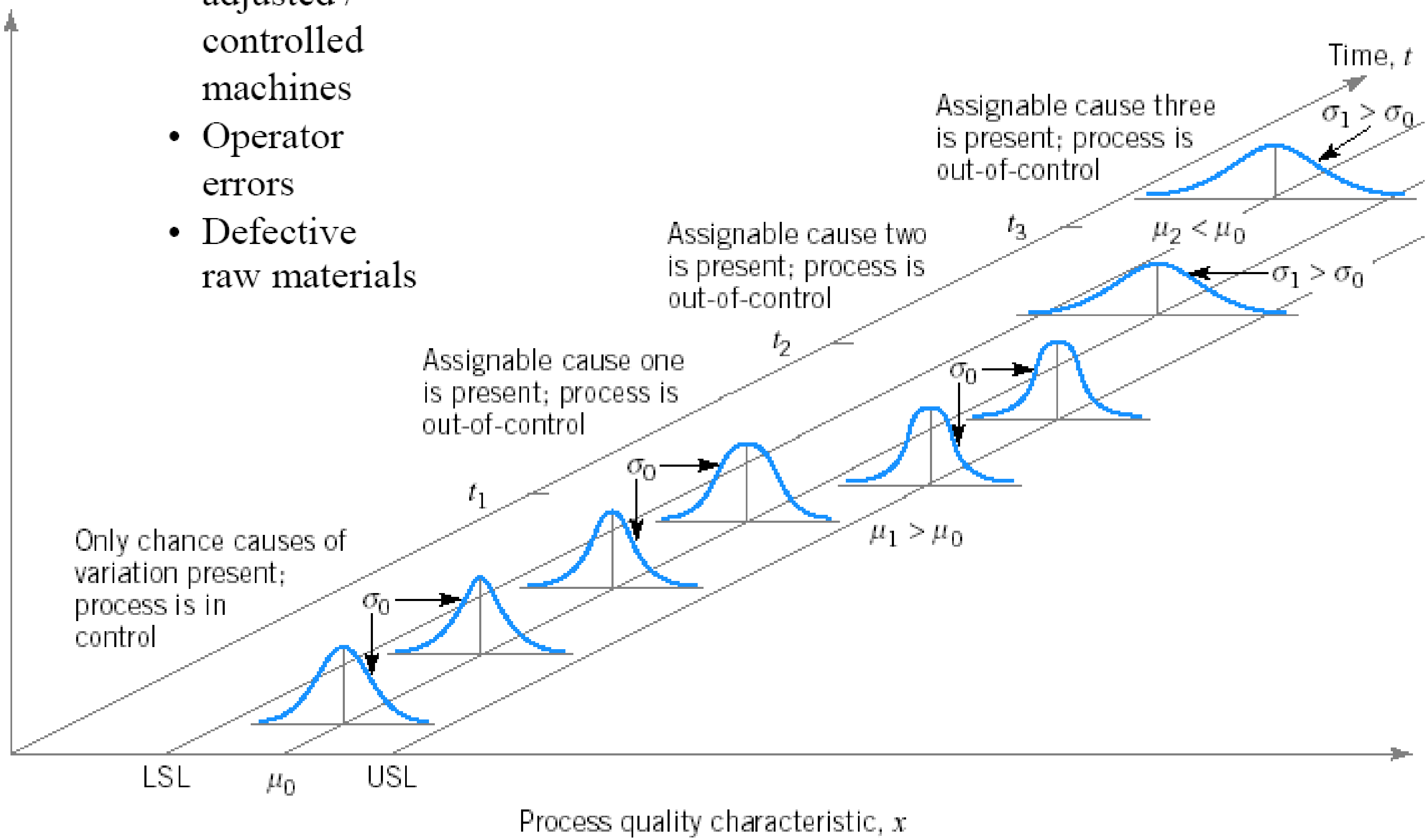
- A process that is operating with only chance causes of variation present is said to be in statistical control.

- A process that is operating in the presence of assignable causes is said to be out of control.

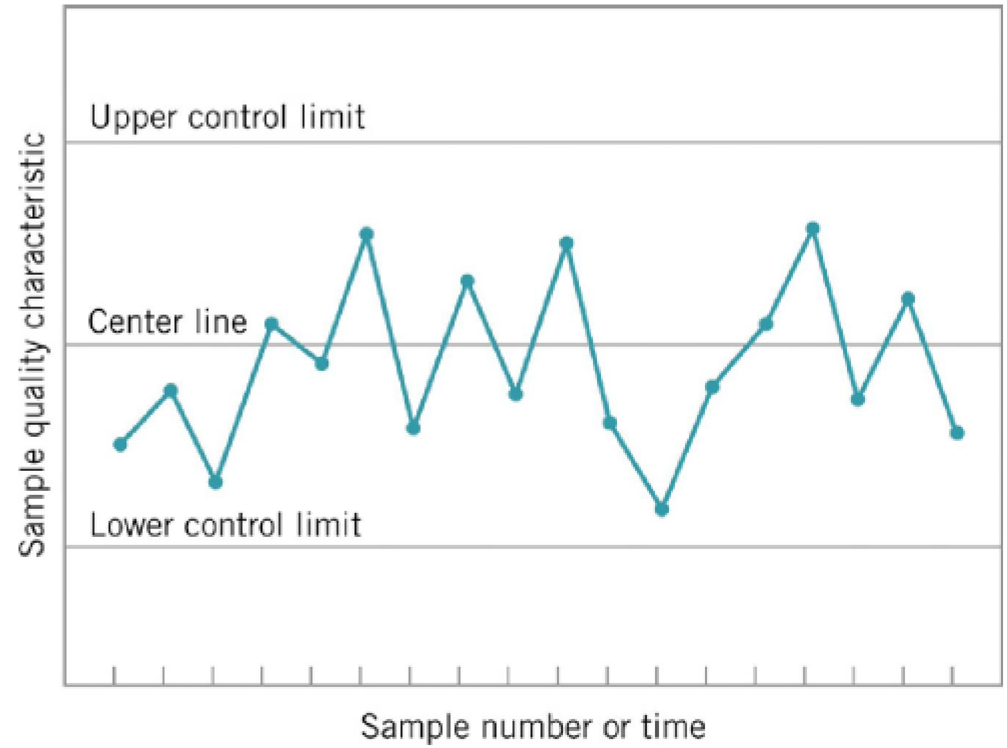
- The eventual goal of SPC is reduction or elimination of variability in the process by identification of assignable causes.

3 sources of variability

- Improperly adjusted / controlled machines
- Operator errors
- Defective raw materials



- A control chart contains
  - A center line
  - An **upper control limit**
  - A **lower control limit**
- Process is in control
  - No action is necessary
- Process is out of control
  - Investigation / action are required to find / eliminate assignable causes
- Close connection between **control charts** and **hypothesis testing**



- A point that plots within the control limits indicates the process is in control
- A point that plots outside the control limits is evidence that the process is out of control

Purpose of Control Charts

- Quickly detect process shifts -> Identify assignable causes

  -> Take corrective actions (before many nonconforming units are manufactured)

  -> Reduce process variability -> Improve process quality

  -> Maximize product quality -> Satisfy customers

  -> Gain market share

- That is, a control chart is an efficient on-line process-monitoring technique.

Additional Purposes of Control Charts

- Control charts may also be used to estimate the parameters of a production process and consequently determine process capability.

Photolithography Example

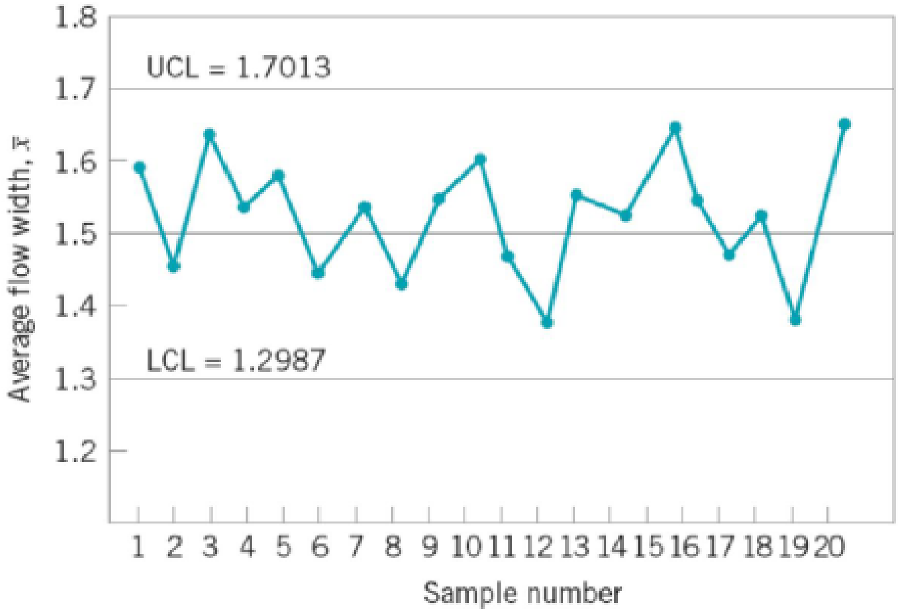


FIGURE 5.3 $\bar{x}$ control chart for flow width.

- Process is monitored by average flow width
  - Sample size of 5 wafers
  - Process mean is 1.5 microns
  - Process standard deviation is 0.15 microns
- Note that all plotted points fall inside the control limits
  - Process is considered to be in statistical control

The $\boxed{\text{process mean is 1.5}}$ microns, and the process standard deviation is $\boxed{\sigma = 0.15}$ microns. Now if samples of size $\boxed{n = 5}$ are taken, the standard deviation of the sample average $\bar{x}$ is

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} = \frac{0.15}{\sqrt{5}} = 0.0671$$

Therefore, if the process is in control with a mean flow width of 1.5 microns, then by using the central limit theorem to assume that $\bar{x}$ is approximately normally distributed, we would expect $\boxed{100(1-\alpha)\%}$ of the sample means $\bar{x}$ to fall between $\boxed{1.5 + Z_{\alpha/2}(0.0671)}$ and $\boxed{1.5 - Z_{\alpha/2}\,(0.0671)}$. We will arbitrarily choose the constant $\boxed{Z_{\alpha/2} \text{ to be } 3}$, so that the upper and lower control limits become

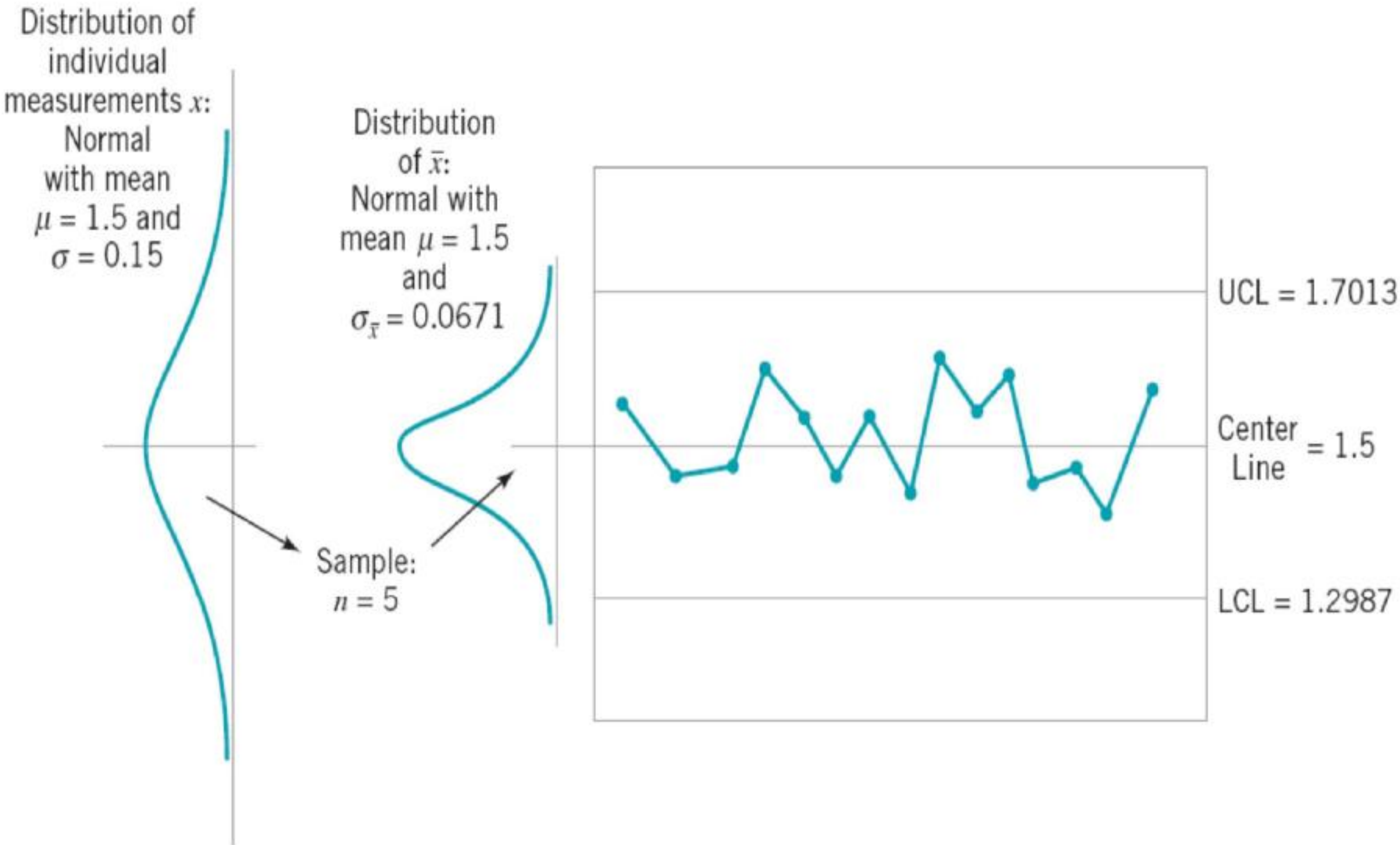
$$\text{UCL} = 1.5 + 3(0.0671) = 1.7013$$

and

$$\text{LCL} = 1.5 - 3(0.0671) = 1.2987$$

as shown on the control chart. These are typically called **"three-sigma"[2] control limits.**

Relationship between the process and the control chart



How the control chart works.

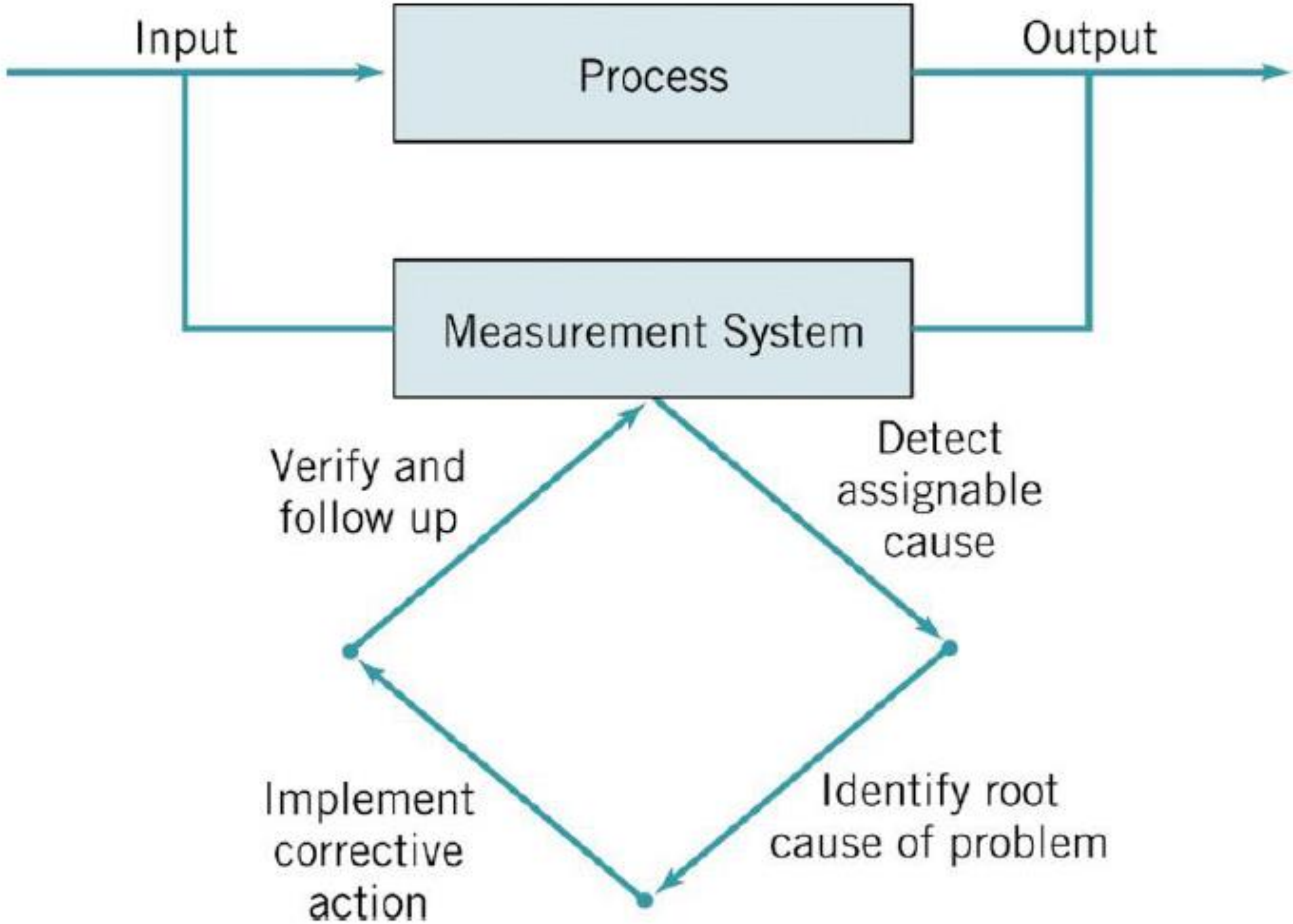
Shewhart Control Chart Model

We may give a general **model** for a control chart. Let $\boxed{w}$ be a sample statistic that measures some quality characteristic of interest, and suppose that the mean of w is $\boxed{\mu_w}$ and the standard deviation of w is $\boxed{\sigma_w}$. Then the center line, the upper control limit, and the lower control limit become

$$\begin{aligned} \text{UCL} &= \mu_w + L\sigma_w \\ \text{Center line} &= \mu_w \\ \text{LCL} &= \mu_w - L\sigma_w \end{aligned} \tag{5.1}$$

where $\boxed{L \text{ is the “distance”}}$ of the control limits from the center line, expressed in standard deviation units. This general theory of control charts was first proposed by Walter A. Shewhart, and control charts developed according to these principles are often called **Shewhart control charts**.

Use of control chart to improve the process



Choice of Control Limits

Three-Sigma Limits

- The use of 3-sigma limits generally gives good results in practice.
- If the distribution of the quality characteristic is reasonably well approximated by the normal distribution, then the use of 3-sigma limits is applicable.
- These limits are often referred to as action limits.

Choice of Control Limits

Warning Limits on Control Charts

- Warning limits (if used) are typically set at 2 standard deviations from the mean.
- If one or more points fall between the warning limits and the control limits, or close to the warning limits the process may not be operating properly.
- Good thing: warning limits often increase the *sensitivity* of the control chart.
- Bad thing: warning limits could result in an increased risk of false alarms.

Sample Size and Sampling Frequency

Average Run Length

- The average run length (ARL) is a very important way of determining the appropriate sample size and sampling frequency.
- Let p = probability that any point exceeds the control limits. Then,

$$\text{ARL} = \frac{1}{p}$$

Sample Size and Sampling Frequency

Illustration

- Consider a problem with control limits set at 3standard deviations from the mean. The probability that a point plots beyond the control limits is again, 0.0027 (i.e., p = 0.0027). Then the average run length is

$$\mathrm{ARL} = \frac{1}{0.0027} = 370$$

Sample Size and Sampling Frequency

What does the ARL tell us?

- The average run length gives us the length of time (or number of samples) that should plot in control before a point plots outside the control limits.

- For our problem, even if the process remains in control, an out-of-control signal will be generated every 370 samples, on average.

Rational Subgroups

Selection of Rational Subgroups

- Sample produced at the same time – consecutive units
  - Provides a “snapshot” of the process.
  - Effective at detecting process shifts.
- Select a random sample over the entire sampling interval. (Sample representing all units produced since last sample)
  - Can be effective at detecting if the mean has wandered out-of-control and then back in-control.
  - Often used to make decisions about acceptance of product

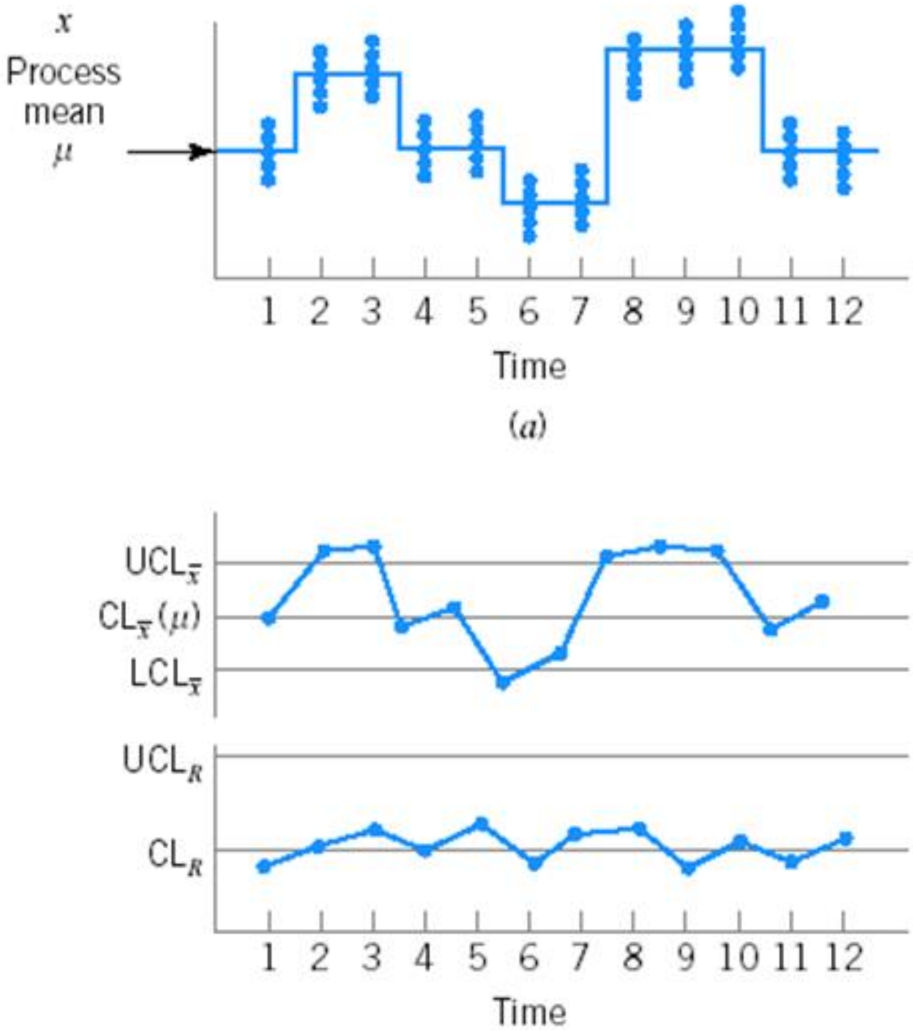


Figure The "snapshot" approach to rational subgroups. (*a*) Behavior of the process mean. (*b*) Corresponding $\bar{x}$ and R control charts.

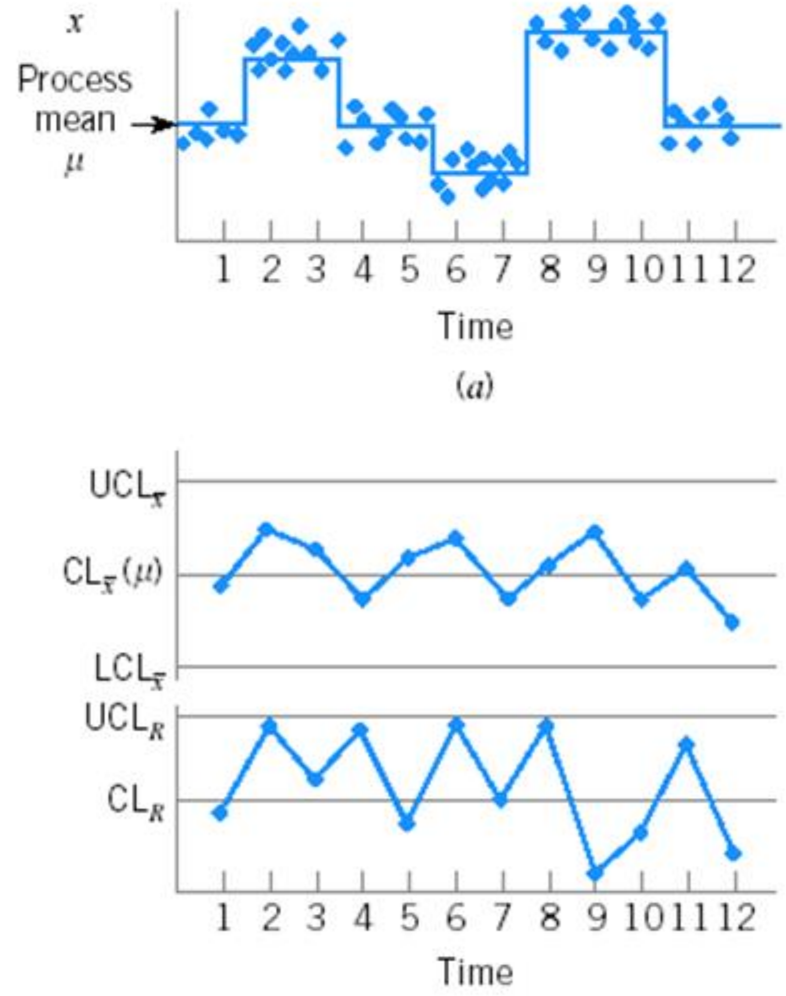


Figure The random sample approach to rational subgroups. (*a*) Behavior of the process mean. (*b*) Corresponding $\bar{x}$ and R control charts.

Analysis of Patterns on Control Charts

Nonrandom patterns can indicate out-of-control conditions

- Patterns such as cycles, trends, are often of considerable diagnostic value
- Look for “runs” - this is a sequence of observations of the same type (all above the center line, or all below the center line)
- Runs of say 8 observations or more could indicate an out-of-control situation.
  - Run up: a series of observations are increasing
  - Run down: a series of observations are decreasing

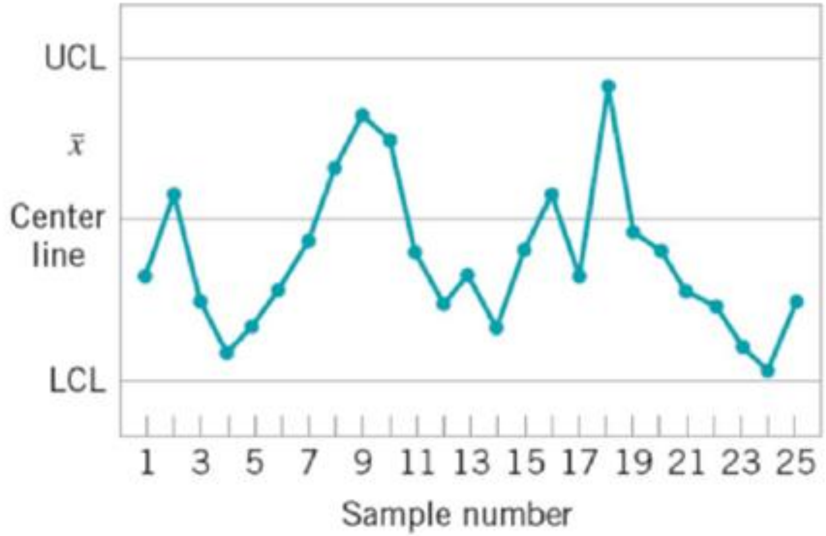


FIGURE An $\bar{x}$ control chart.

- Pattern is very nonrandom in appearance
- 19 of 25 points plot below the center line, while only 6 plot above
- From 4^{th} point, 5 points in a row increase in magnitude, a *run up*
- There is also an unusually long *run down* beginning with 18^{th} point

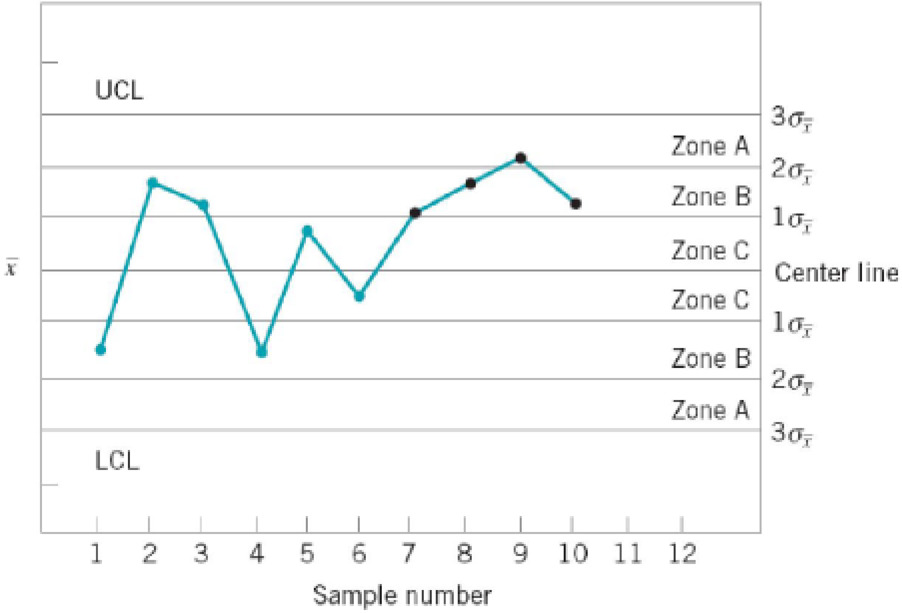
Pattern Recognition

The Western Electric Handbook (1956) suggests a set of decision rules for detecting nonrandom patterns on control charts. Specifically, it suggests concluding that the process is out of control if either

1. One point plots outside the three-sigma control limits;
2. Two out of three consecutive points plot beyond the two-sigma warning limits;
3. Four out of five consecutive points plot at a distance of one-sigma or beyond from the center line;

or

4. Eight consecutive points plot on one side of the center line.



■ **FIGURE** The Western Electric or zone rules, with the last four points showing a violation of rule 3.

Some Sensitizing Rules for Shewhart Control Charts

Standard Action Signal:	**1.** One or more points outside of the control limits.	Western Electric Rules
	2. Two of three consecutive points outside the two-sigma warning limits but still inside the control limits.	
	3. Four of five consecutive points beyond the one-sigma limits.	
	4. A run of eight consecutive points on one side of the center line.	
	5. Six points in a row steadily increasing or decreasing.	
	6. Fifteen points in a row in zone C (both above and below the center line).	
	7. Fourteen points in a row alternating up and down.	
	8. Eight points in a row on both sides of the center line with none in zone C.	
	9. An unusual or nonrandom pattern in the data.	
	10. One or more points near a warning or control limit.	

The Rest of the “Magnificent Seven”

- The control chart is most effective when integrated into a comprehensive SPC program.
- The seven major SPC problem-solving tools should be used routinely to identify improvement opportunities.
- The seven major SPC problem-solving tools should be used to assist in reducing variability and eliminating waste.

The Rest of the "Magnificent Seven"

Check Sheets

- See example after,
- Useful for collecting historical or current operating data about the process under investigation.
- Can provide a useful time-oriented summary of data

Check Sheet

CHECK SHEET
DEFECT DATA FOR 2002–2003 YTD

Part No.: TAX-41
Location: Bellevue
Study Date: 6/5/03
Analyst: TCB

	2002												2003					
Defect	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	Total
Parts damaged		1		3	1	2		1		10	3		2	2	7	2		34
Machining problems			3	3				1	8		3		8	3				29
Supplied parts rusted			1	1		2	9											13
Masking insufficient		3	6	4	3	1												17
Misaligned weld	2																	2
Processing out of order	2															2		4
Wrong part issued		1						2										3
Unfinished fairing			3															3
Adhesive failure				1							1		2			1	1	6
Powdery alodine					1													1
Paint out of limits						1								1				2
Paint damaged by etching			1															1
Film on parts						3		1	1									5
Primer cans damaged								1										1
Voids in casting									1	1								2
Delaminated composite										2								2
Incorrect dimensions											13	7	13	1		1	1	36
Improper test procedure										1								1
Salt-spray failure													4			2		4
TOTAL	4	5	14	12	5	9	9	6	10	14	20	7	29	7	7	6	2	166

Figure 4-16 A check sheet to record defects on a tank used in an aerospace application.

4-4. The Rest of the "Magnificent Seven"

Pareto Chart

- The Pareto chart is a frequency distribution (or histogram) of attribute data arranged by category.
- Plot the frequency of occurrence of each defect type against the various defect types.
- See example for the tank defect data, Figure 4-17
- There are many variations of the Pareto chart; see Figure 4-18

Pareto Chart

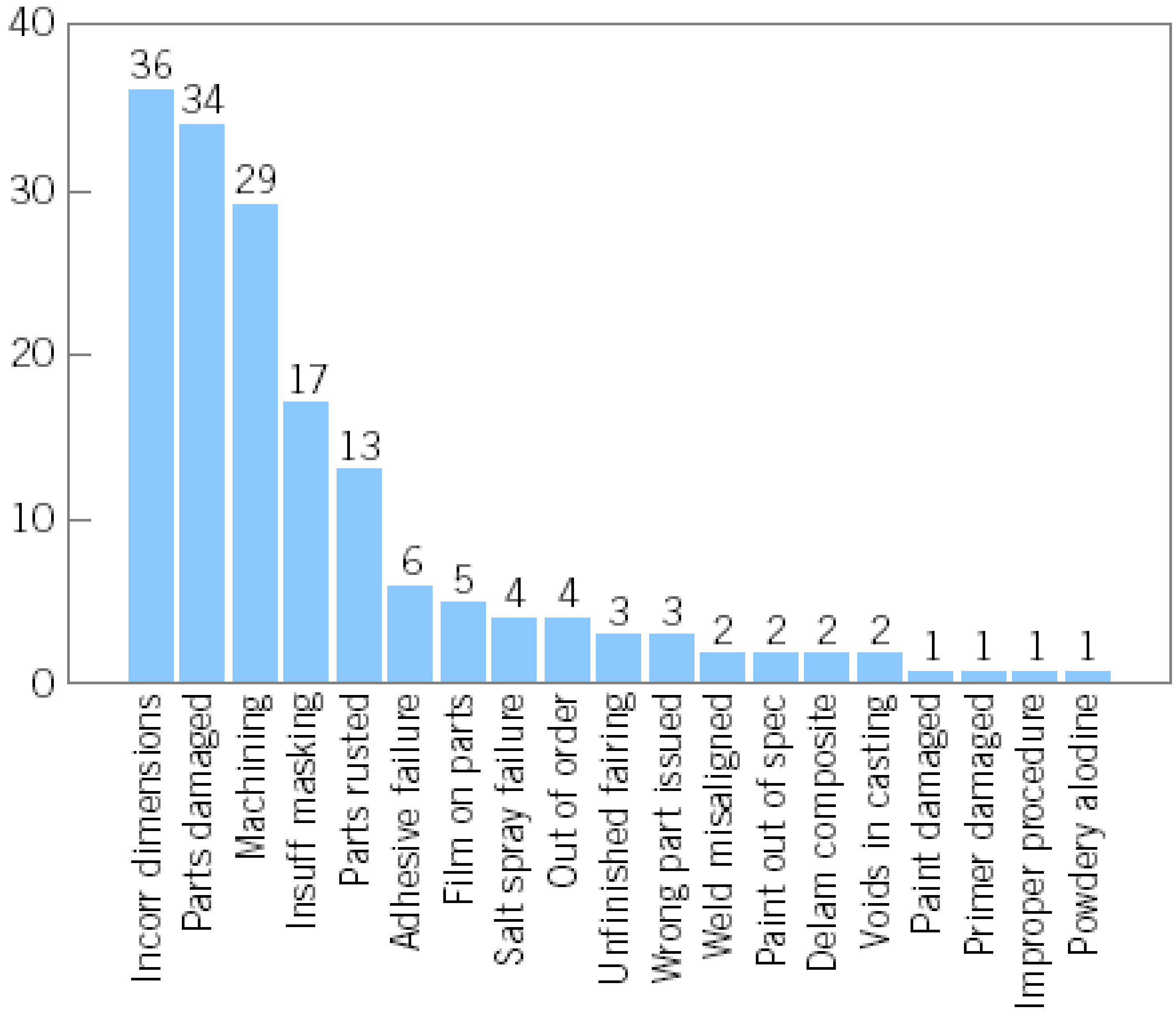


Figure 4-17 Pareto chart of the tank defect data.

The Rest of the “Magnificent Seven”

Cause and Effect Diagram

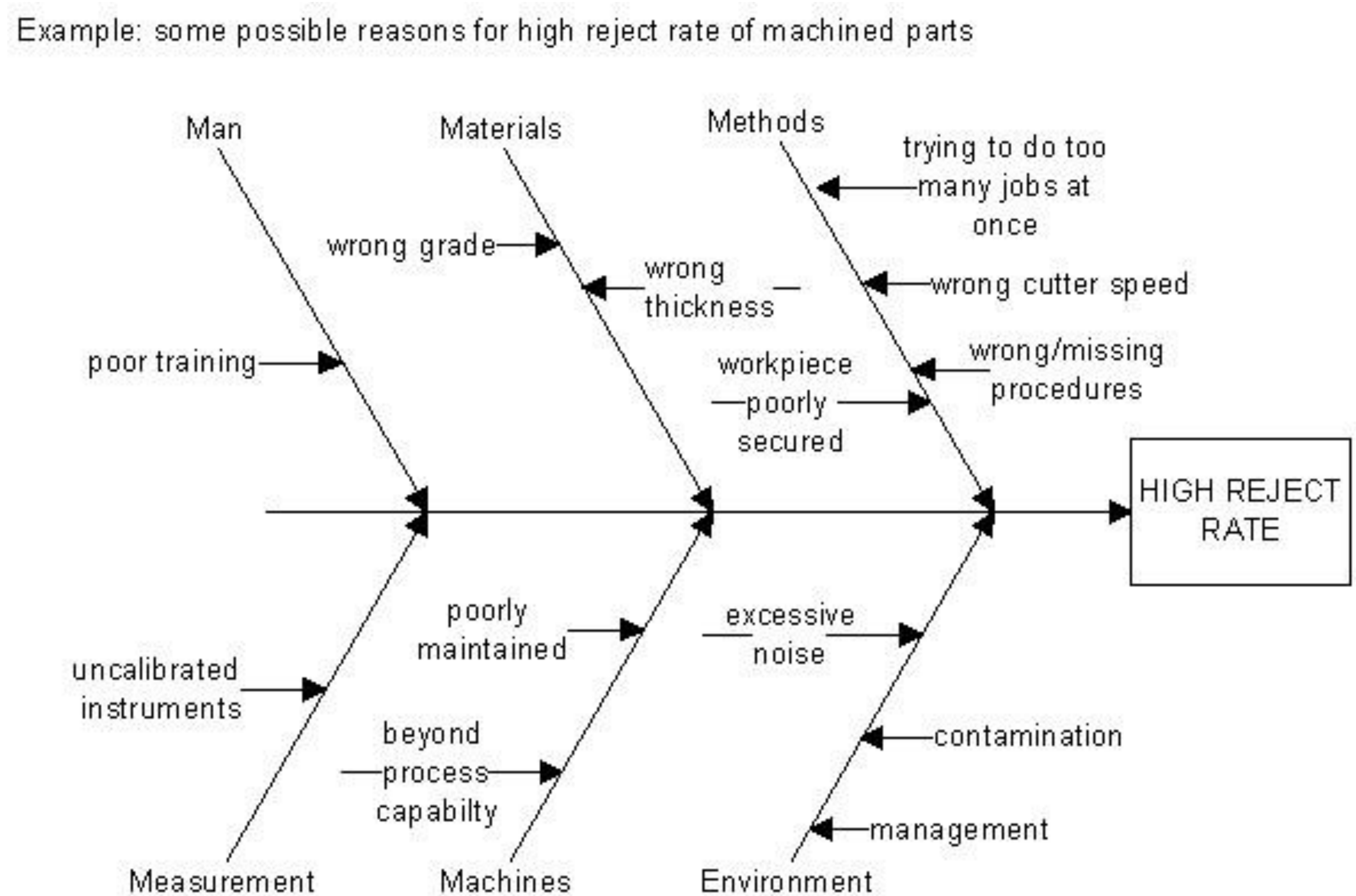
- Once a defect, error, or problem has been identified and isolated for further study, potential causes of this undesirable effect must be analyzed.

- Cause and Effect Analysis is a technique for identifying all the possible causes (inputs) associated with a particular problem / effect (output) before narrowing down to the small number of main, root causes which need to be addressed.

- Cause and effect diagrams are sometimes called fishbone diagrams because of their appearance

Fishbone diagrams help to identify the "6 Ms" (potential causes) that may have contributed to the undesirable condition or problem.

- Man (People)
- Machines
- Mother Nature (Environment)
- Methods
- Materials
- Measurements

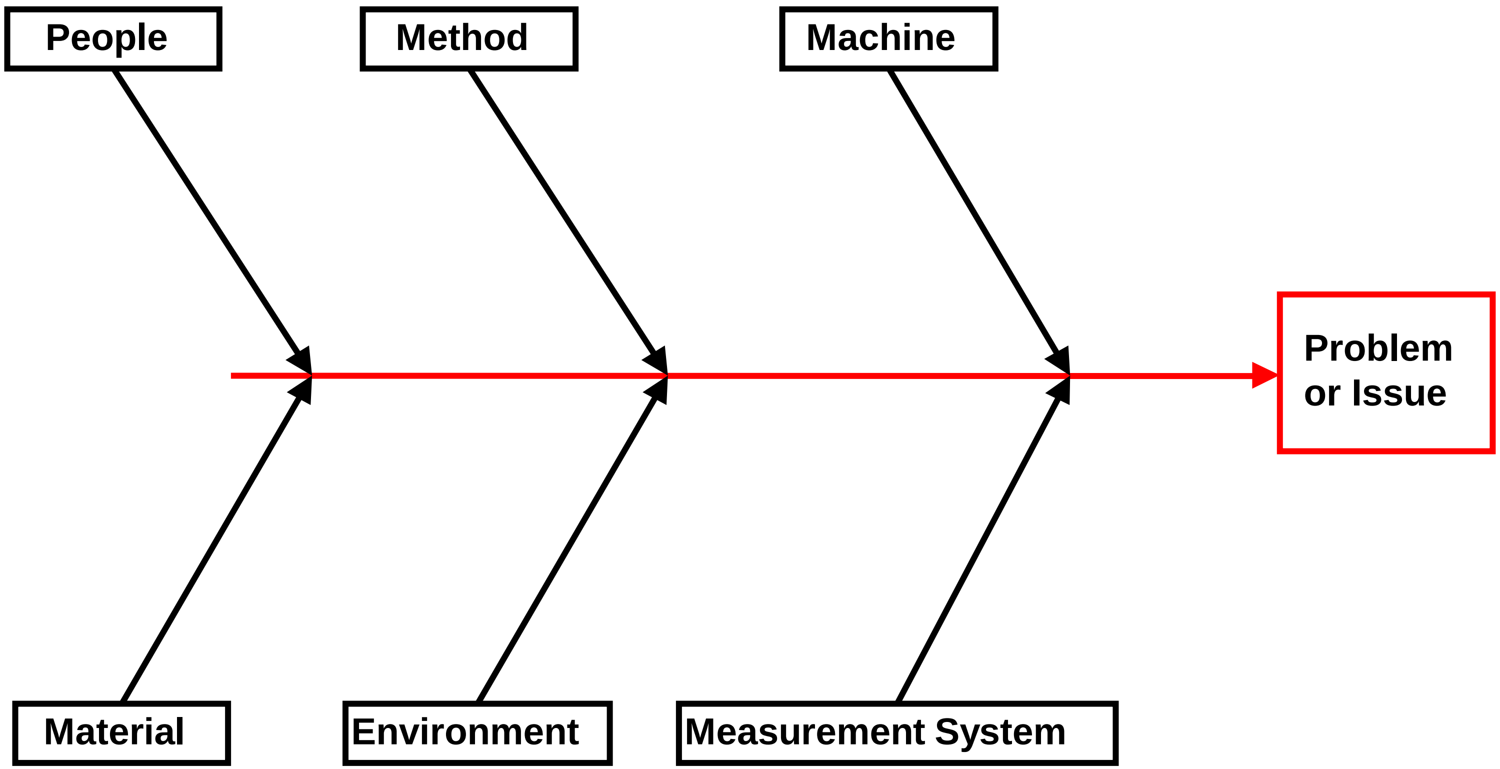


How to Construct a Cause-and-Effect Diagram

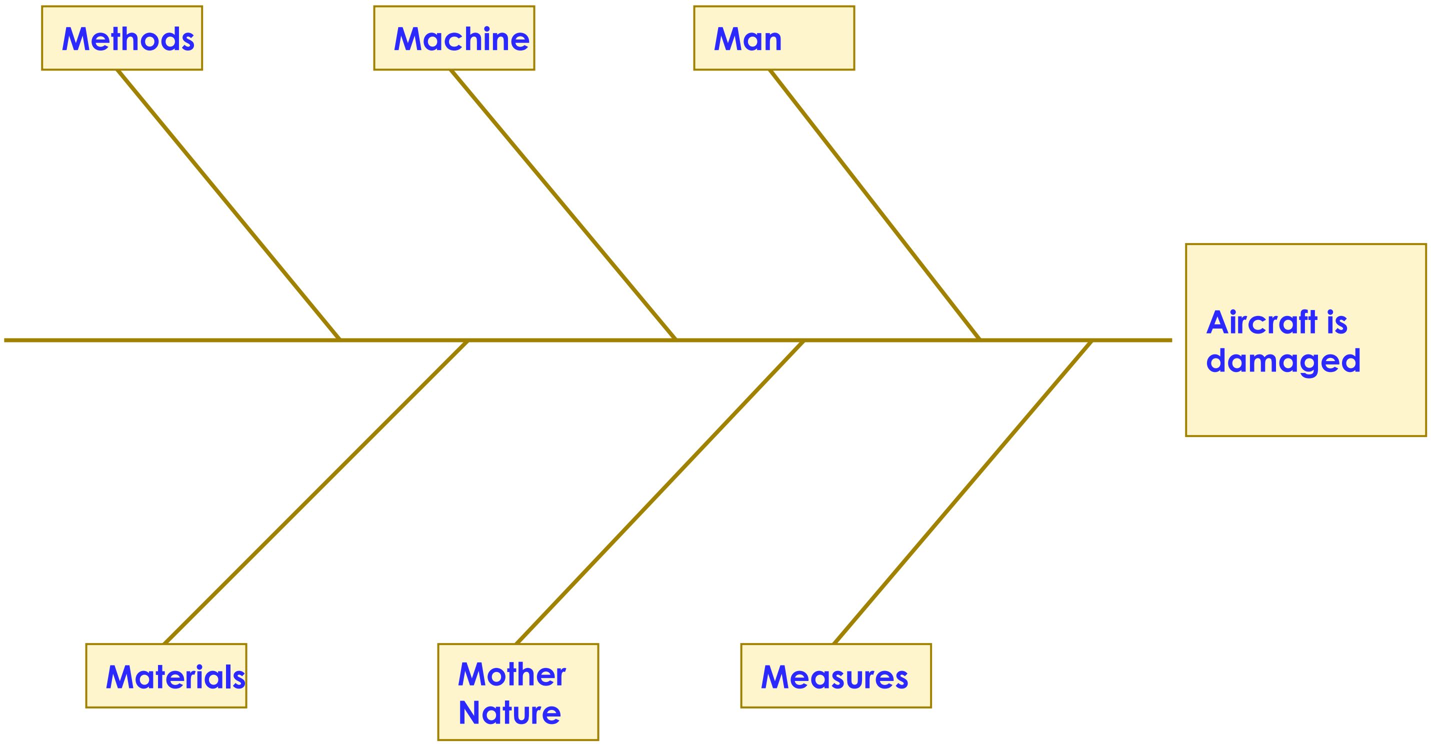
1. Define the problem or effect to be analyzed.
2. Form the team to perform the analysis. Often the team will uncover potential causes through brainstorming.
3. Draw the effect box and the center line.
4. Specify the major potential cause categories and join them as boxes connected to the center line.
5. Identify the possible causes and classify them into the categories in step 4. Create new categories, if necessary.
6. Rank order the causes to identify those that seem most likely to impact the problem.
7. Take corrective action.

Event: You are operating a tug that is towing a Gulfstream IV. Suddenly, the tug becomes uncontrollable, which causes the tow hitch to break and extensive damage to the aircraft nose gear results.

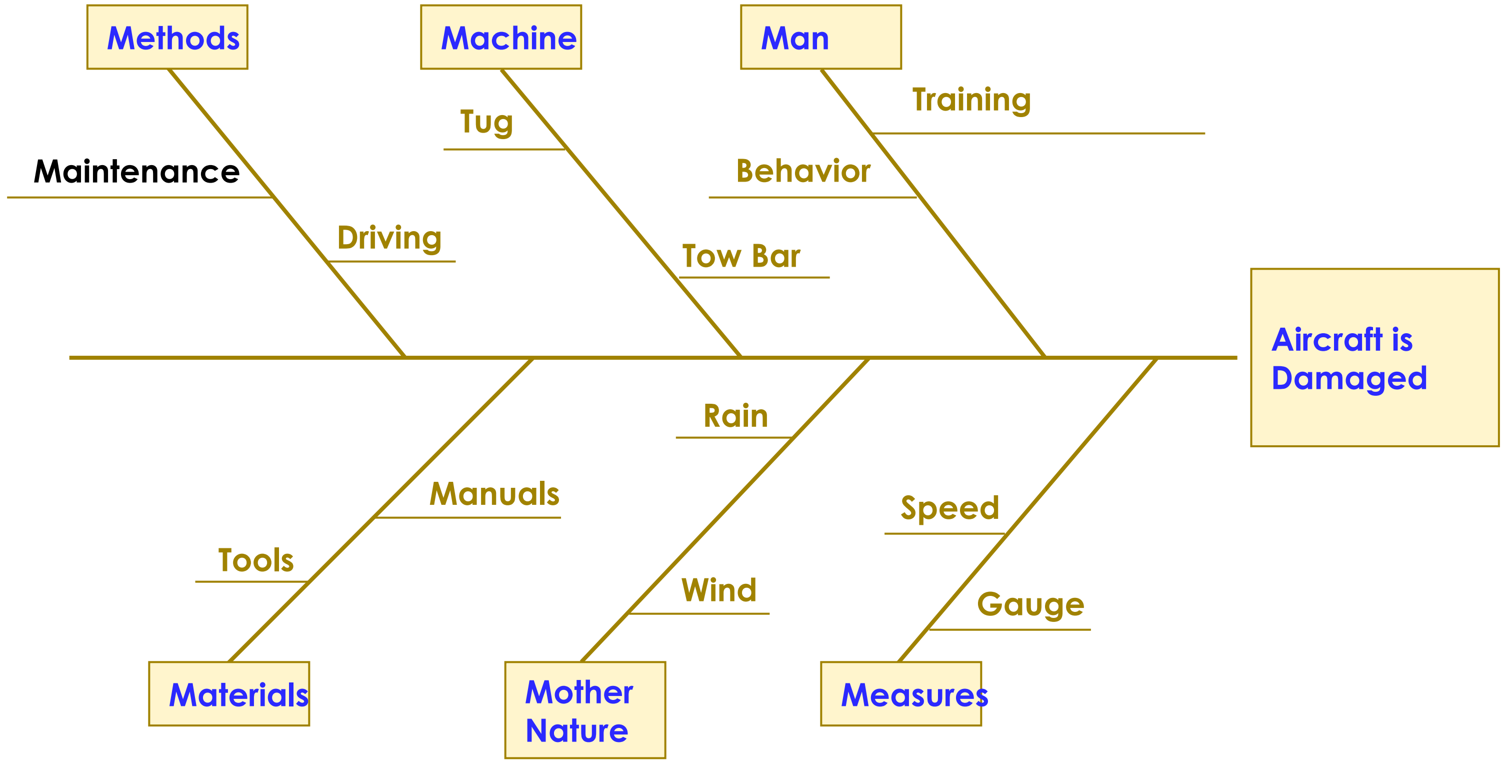
- **Place the effect at the head of the "fish"**
  - **Include the 6 recommended categories shown below**



2. Label each "bone" of the fish.



3. Through brainstorming, identify factors in each category that could affect the undesirable occurrence.

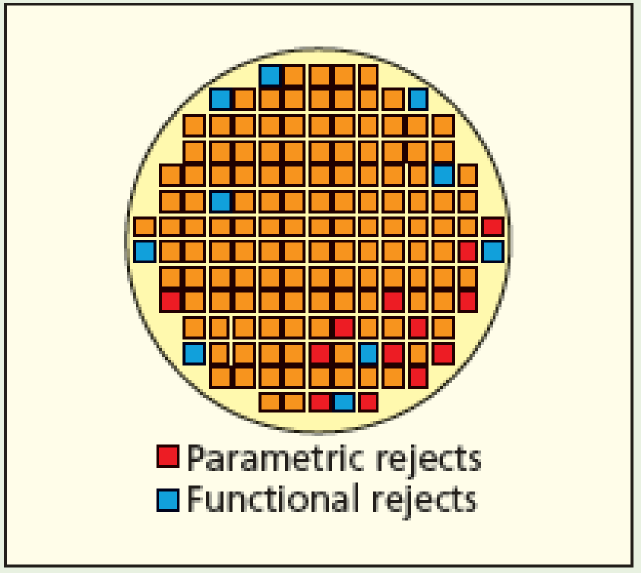


The Rest of the "Magnificent Seven"

Defect Concentration Diagram

- A defect concentration diagram is a picture of the unit, showing all relevant views.
- Various types of defects that can occur are drawn on the picture
- See example, Next Figure
- The diagram is then analyzed to determine if the location of the defects on the unit provides any useful information about the potential causes of the defects.

Defect Concentration Diagram



Defect Concentration Diagram Showing the Locations of Rejected Chips on Integrated Circuits

The Rest of the “Magnificent Seven”

Scatter Diagram

- The scatter diagram is a plot of two variables that can be used to identify any potential relationship between the variables.
- The shape of the scatter diagram often indicates what type of relationship may exist.
- See the following example

Scatter Diagram

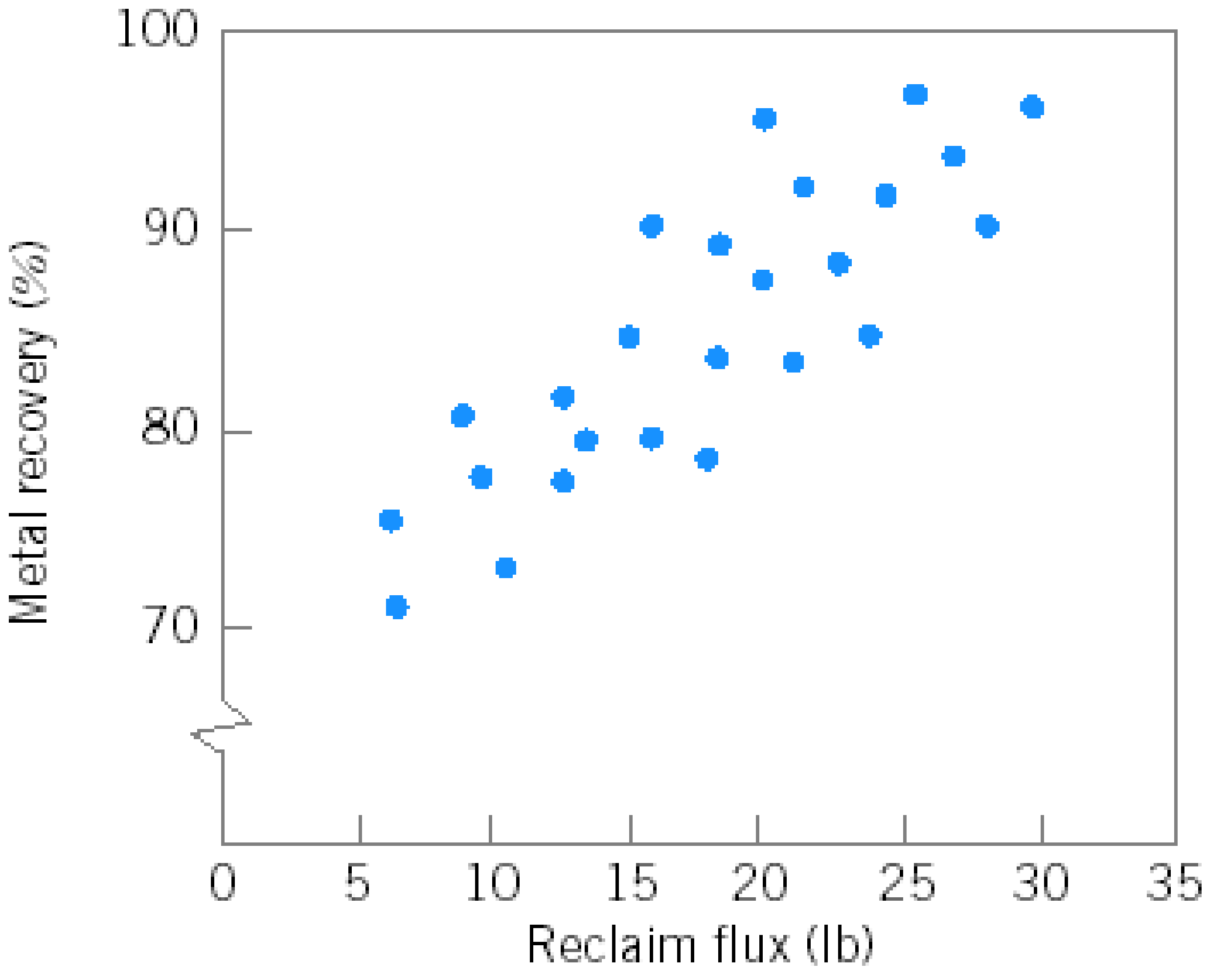


Figure 4-22 A scatter diagram.

Implementing SPC

Elements of a Successful SPC Program

1. Management leadership
2. A team approach
3. Education of employees at all levels
4. Emphasis on reducing variability
5. Measuring success in quantitative (economic) terms
6. A mechanism for communicating successful results throughout the organization