Introduction to Operations Management
运营管理概论

8- Quality

范登波 Thomas VANDENBOGAERDE, CPIM
Thomas.vandenbogaerde@gmail.com
If any question: WeChat: fandengbo85

Defining quality goes beyond « something that doesn't break »

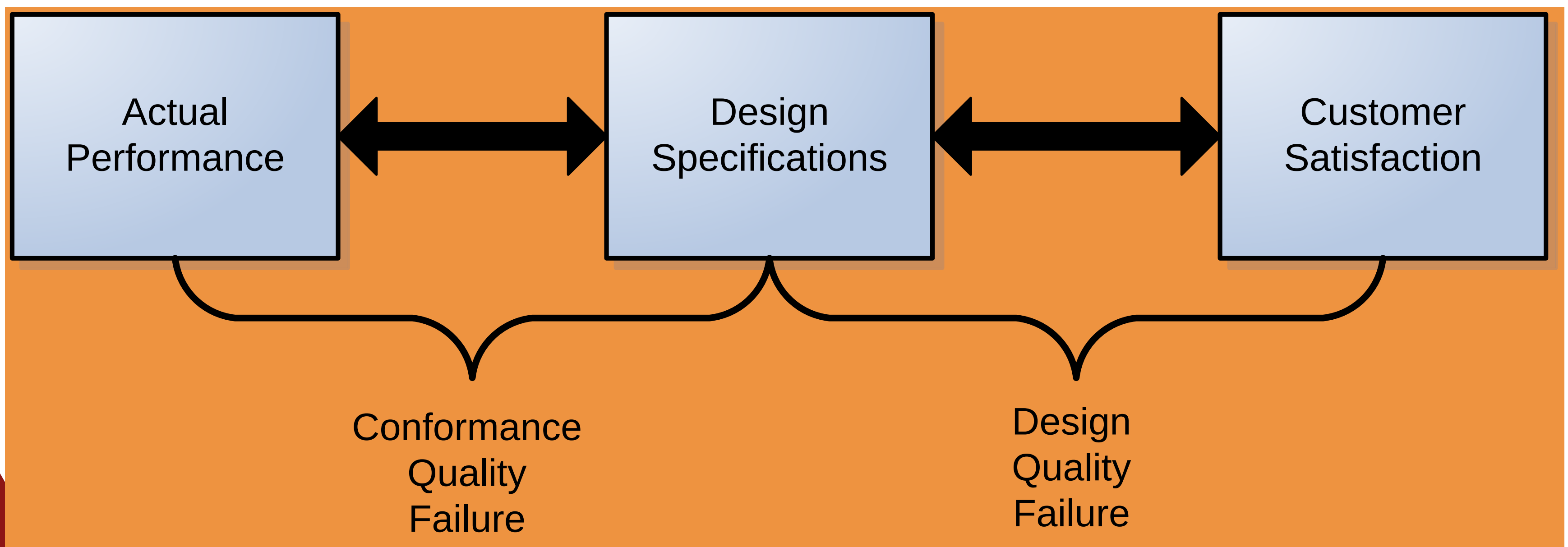
Top 10 definitions of quality / TABLE 1

1.	Efficiently providing products and services that meet or exceed customer expectations.
2.	Adding customer value.
3.	Continuously measuring the improvement of processes and services for customers.
4.	Acting as promised and reporting failures.
5.	Doing the right thing at the right time in the right way with the right people.
6.	Ensuring customers come back and products do not.
7.	Providing the best value to customers by improving everyday activities and processes.
8.	Beyond delivering what the customer wants, anticipating what the customer will want when he or she knows the possibilities.
9.	Delivering customer value across the organization through best-in-class products, services and support.
10.	Meeting and exceeding the expectations of clients, employees and relevant constituencies in the community.

Source: ASQ, "Discoveries," ASQ Global State of Quality Study, 2013, http://asq.org/global-state-of-quality/reports.aspx.

Quality and Failure

1. **Design quality**—refers to how closely the characteristics of a product or service meet the needs and wants of customers
2. **Conformance quality**—refers to the performance of a product or service relative to its design and product specifications



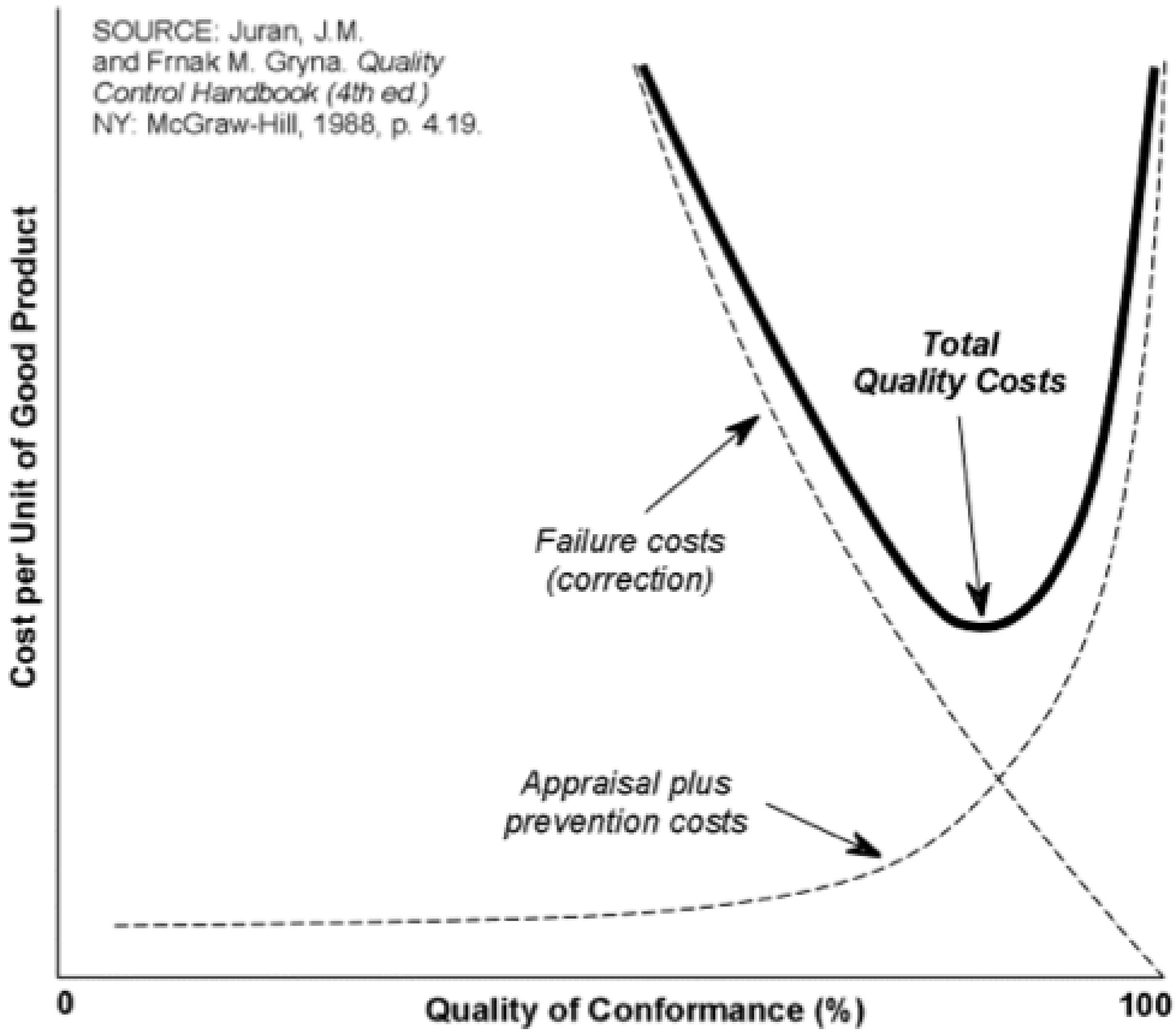
Quality as a Competitive Tool

- Quality—the total features and characteristics of a product or a service made or performed according to specifications to satisfy customers at the time of purchase and during use.
- A quality focus reduces costs and increases customer satisfaction.
- Focusing on the quality of a product will generally build expertise in producing it, lower the costs of making it, create customer satisfaction for customers using it, and generate higher future revenues for the company selling it.

Consider a 99% quality level

- 5000 incorrect surgical operations per week!
- 200,000 wrong drug prescriptions per year!
- 2 crash landings at most major airports each day!
- 20,000 lost articles of mail per hour!

Trade of between the Cost of Quality and the Cost of non Quality



Measuring non quality

Advantages of COQ (Financial) Measures

- COQ focuses managers' attention on the costs of poor quality.
- COQ measures assist in problem solving by comparing costs and benefits of different quality-improvement programs and setting priorities for cost reduction.
- COQ provides a single, summary measure of quality performance for evaluating trade-offs among the costs of prevention, appraisal, internal failure, and external failure.

Advantages of Nonfinancial Measures of Quality

- Nonfinancial measures of quality are often easy to quantify and understand.
- Nonfinancial measures direct attention to physical processes and to areas that need improvement.
- Nonfinancial measures provide immediate short-run feedback on whether quality-improvement efforts have succeeded.
- Nonfinancial measures are useful indicators of future long-run performance.

The Financial Perspective: Costs of Quality (COQ)

- Four categories of quality costs:

1. **Prevention costs**—incurred to preclude the production of products that do not conform to specifications
2. **Appraisal costs**—incurred to detect which of the individual units of products do not conform to specifications
3. **Internal failure costs**—incurred on defective products before they are shipped to customers
4. **External failure costs**—incurred on defective products after they are shipped to customers

Prevention Costs	Appraisal Costs	Internal Failure Costs	External Failure Costs
Design engineering	Inspection	Spoilage	Customer support
Process engineering	Online product manufacturing and process inspection	Rework	Manufacturing/ process engineering for external failures
Supplier evaluations	Product testing	Scrap	Warranty repair costs
Preventive equipment maintenance		Machine repairs	Liability claims
Quality training		Manufacturing/ process engineering on internal failures	
Testing of new materials			

Activity-Based COG Analysis Illustration

	A	B	C	D	E	F	G
1	**PANEL A: COQ REPORT**						**Percentage of**
2		**Cost Allocation**		**Quantity of Cost**		**Total**	**Revenues**
3	**Cost of Quality and Value-Chain Category**	**Rate[a]**		**Allocation Base**		**Costs**	**(5) = (4) ÷**
4	**(1)**	**(2)**		**(3)**		**(4) = (2) x (3)**	**$300,000,000**
5	*Prevention costs*						
6	Design engineering (R&D/Design)	$ 80	per hour	40,000	hours	$ 3,200,000	1.1%
7	Process engineering (R&D/Design)	$ 60	per hour	45,000	hours	2,700,000	0.9%
8	Total prevention costs					5,900,000	2.0%
9	*Appraisal costs*						
10	Inspection (Manufacturing)	$ 40	per hour	240,000	hours	9,600,000	3.2%
11	Total appraisal costs					9,600,000	3.2%
12	*Internal failure costs*						
13	Rework (Manufacturing)	$100	per hour	100,000	hours	10,000,000	3.3%
14	Total internal failure costs					10,000,000	3.3%
15	*External failure costs*						
16	Customer support (Marketing)	$ 50	per hour	12,000	hours	600,000	0.2%
17	Transportation (Distribution)	$240	per load	3,000	loads	720,000	0.2%
18	Warranty repair (Customer service)	$110	per hour	120,000	hours	13,200,000	4.4%
19	Total external failure costs					14,520,000	4.8%
20	Total costs of quality					$40,020,000	13.3%
21							
22	[a]Amounts assumed.						
23							
24	**PANEL B: OPPORTUNITY COST ANALYSIS**						
25						**Total Estimated**	**Percentage**
26						**Contribution**	**of Revenues**
27	**Cost of Quality Category**					**Margin Lost**	**(3) = (2) ÷**
28	**(1)**					**(2)**	**$300,000,000**
29	*External failure costs*						
30	Estimated forgone contribution margin						
31	and income on lost sales					$12,000,000[b]	4.0%
32	Total external failure costs					$12,000,000	4.0%
33							
34	[b]Calculated as total revenues minus all variable costs (whether output-unit, batch, product-sustaining, or facility-sustaining) on						
35	lost sales in 2008. If poor quality causes Photon to lose sales in subsequent years as well, the opportunity costs will be						
36	even greater.						

Performance Standards (1 process)

σ	PPM	Yield
2	308537	69.1%
3	66807	93.3%
4	6210	99.38%
5	233	99.977%
6	3.4	99.9997%

World Class

Process performance — Defects per million — Long term yield

Performance standards (successives processes)

First Time Yield in multiple stage process

Number of processes	3σ	4σ	5σ	6σ
1	93.32	99.379	99.9767	99.99966
10	50.09	93.96	99.77	99.9966
100	0.1	53.64	97.70	99.966
500	0	4.44	89.02	99.83
1000	0	0.2	79.24	99.66
2000	0	0	62.75	99.32
2955	0	0	50.27	99.0

General Electric

In 1995 GE mandated each employee to work towards achieving 6 sigma

- The average process at GE was 3 sigma in 1995
- In 1997 the average reached 3.5 sigma
- GE's goal was to reach 6 sigma by 2001
- Investments in 6 sigma training and projects reached 45MUS$ in 1998, profits increased by 1.2BUS$

"the most important initiative GE has ever undertaken".

Jack Welch
Chief Executive Officer
General Electric

MOTOROLA

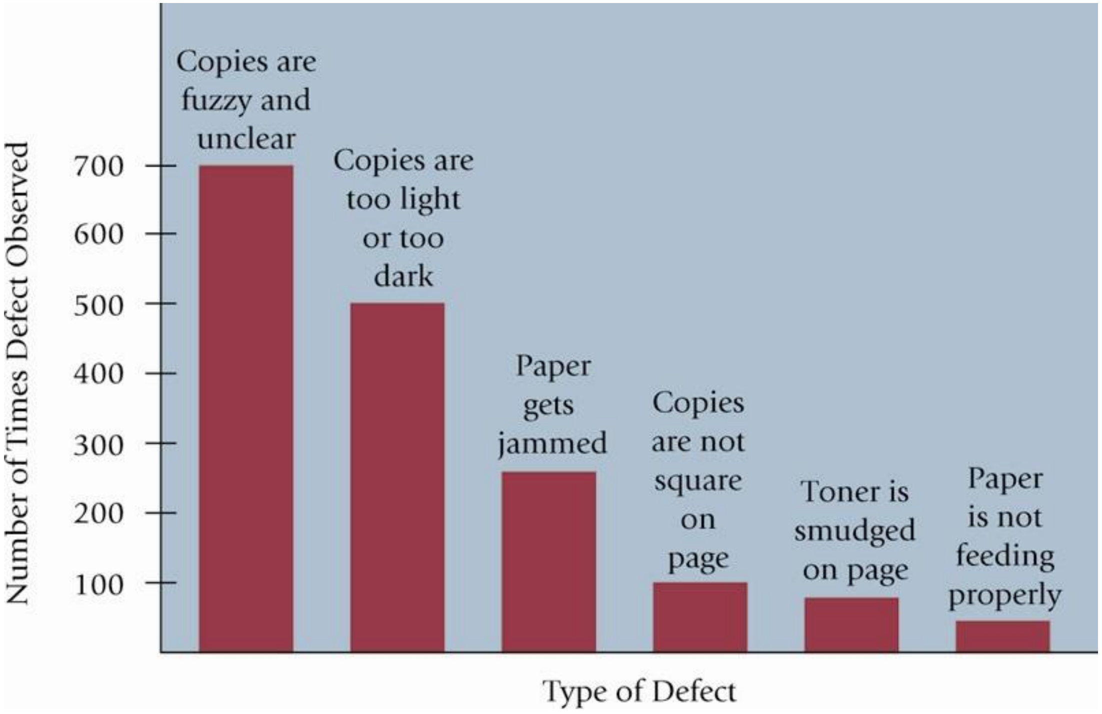
"At Motorola we use statistical methods daily throughout all of our disciplines to synthesize an abundance of data to derive concrete actions…. How has the use of statistical methods within Motorola Six Sigma initiative, across disciplines, contributed to our growth? Over the past decade we have reduced in-process defects by over 300 fold, which has resulted in cumulative manufacturing cost savings of over 11 billion dollars"*.

Robert W. Galvin
Chairman of the Executive Committee
Motorola, Inc.

***From the forward to MODERN INDUSTRIAL STATISTICS by Kenett and Zacks, Duxbury, 1998**

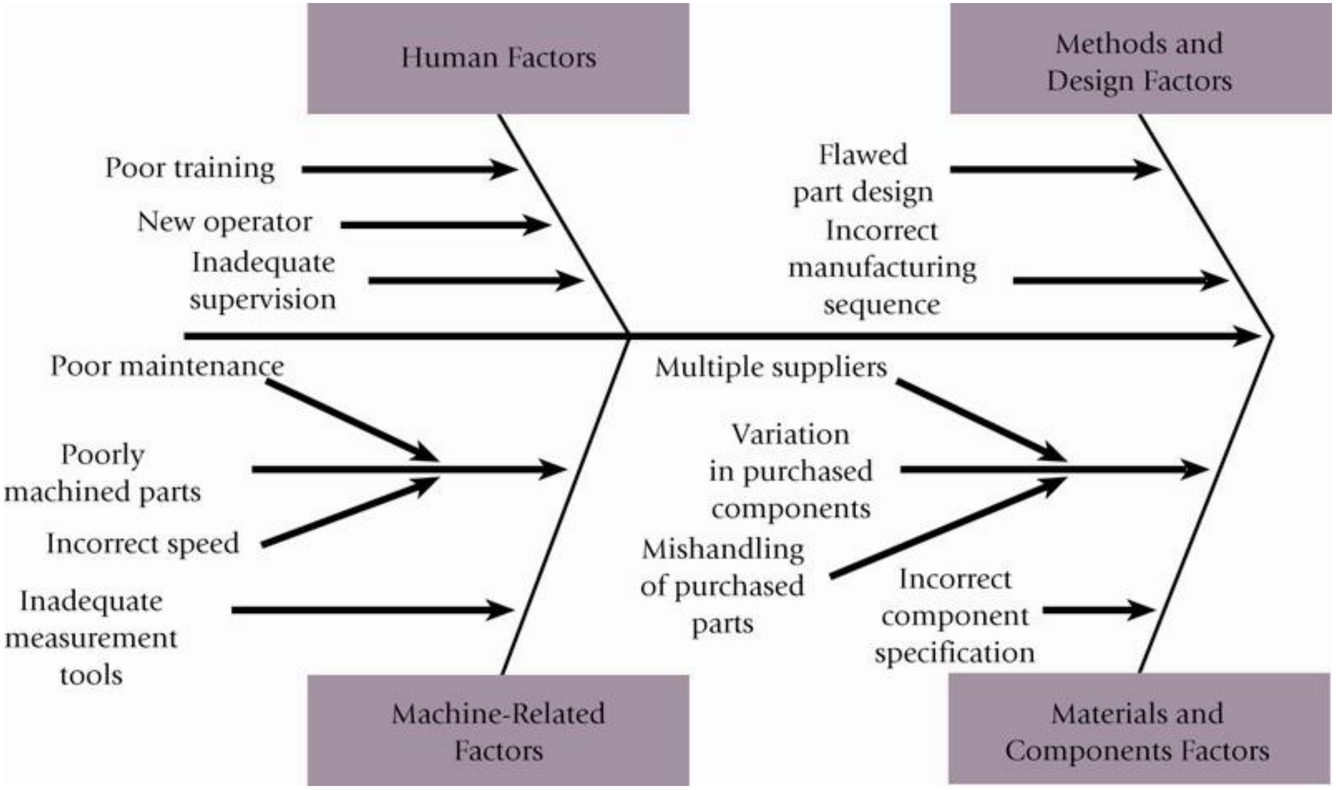
Pareto Diagrams

- Observations outside control limits serve as inputs for Pareto diagrams.
- Pareto diagram—a chart that indicates how frequently each type of defect occurs, ordered from the most frequent to the least frequent.



Cause-and-Effect Diagrams

- Identifies potential causes of defects
- Problems identified by the Pareto diagram are analyzed using cause-and-effect diagrams
- Also called fishbone diagrams because they resemble the bone structure of a fish



Statistical Process Control (SPC)

- Variability is inherent in every process
  - Natural or common causes
  - Special or assignable causes
- Provides a statistical signal when assignable causes are present
- Detect and eliminate assignable causes of variation

Natural Variations

- Also called **common causes**
- Affect virtually all production processes
- Expected amount of variation
- Output measures follow a probability distribution
- For any distribution there is a measure of central tendency and dispersion
- If the distribution of outputs falls within acceptable limits, the process is said to be “in control”

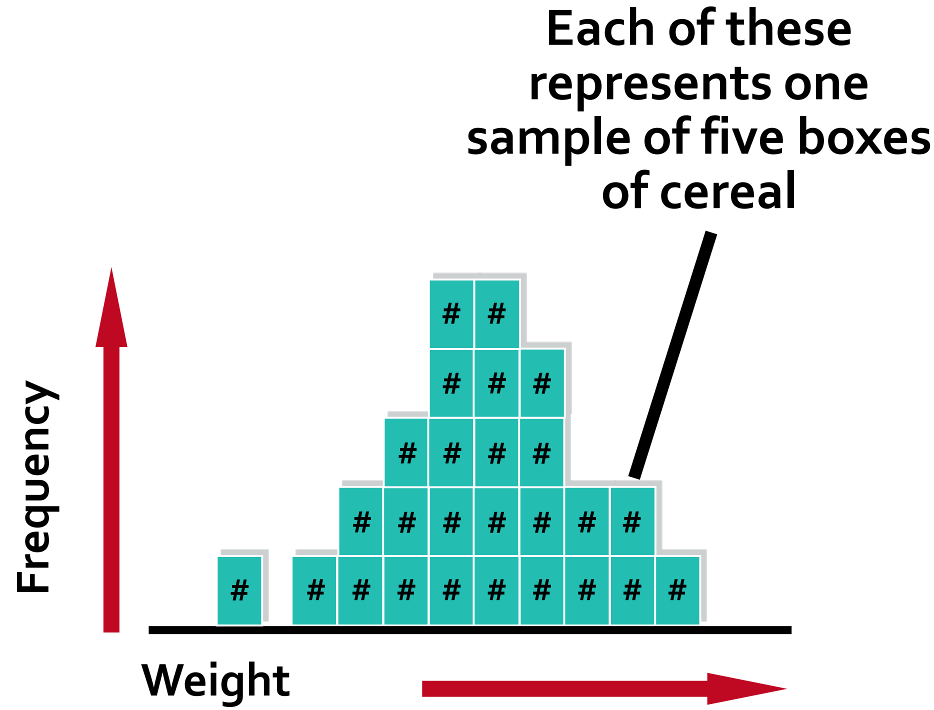
Assignable Variations

- Also called **special causes** of variation
  - Generally this is some change in the process
- Variations that can be traced to a specific reason
- The objective is to discover when assignable causes are present
  - Eliminate the bad causes
  - Incorporate the good causes

Samples

To measure the process, we take samples and analyze the sample statistics following these steps

(a) Samples of the product, say five boxes of cereal taken off the filling machine line, vary from each other in weight

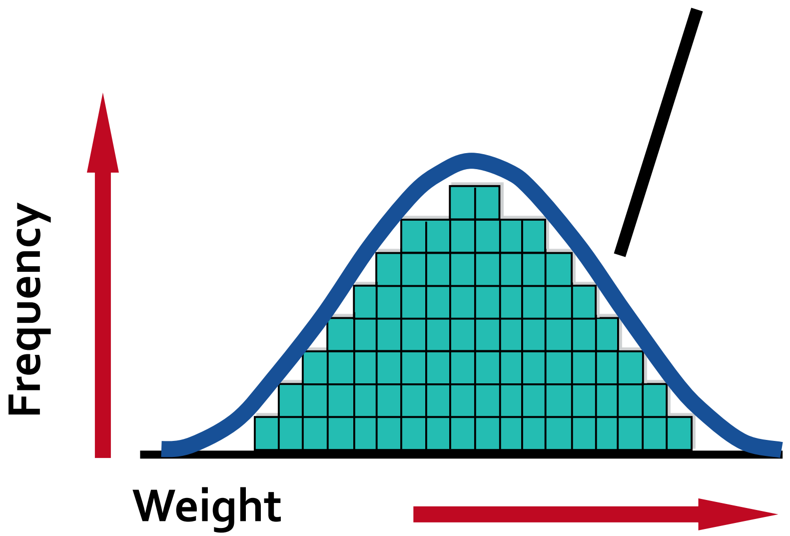


Samples

To measure the process, we take samples and analyze the sample statistics following these steps

(b) After enough samples are taken from a stable process, they form a pattern called a distribution

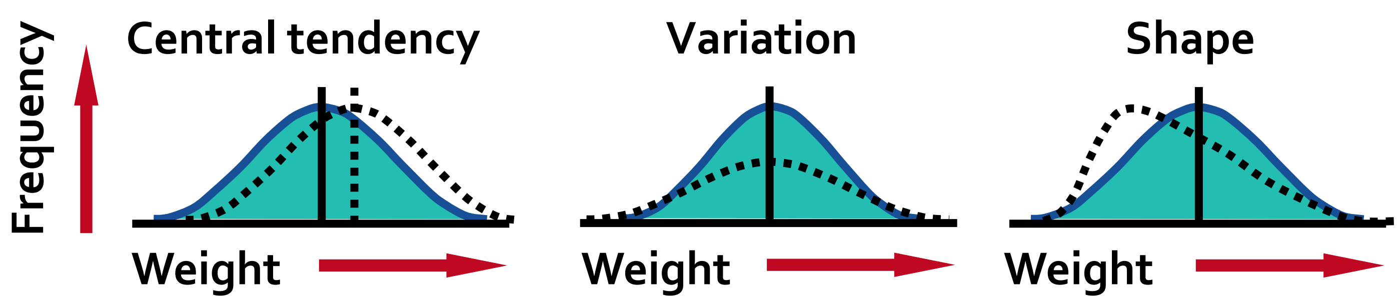
The solid line represents the distribution



Samples

To measure the process, we take samples and analyze the sample statistics following these steps

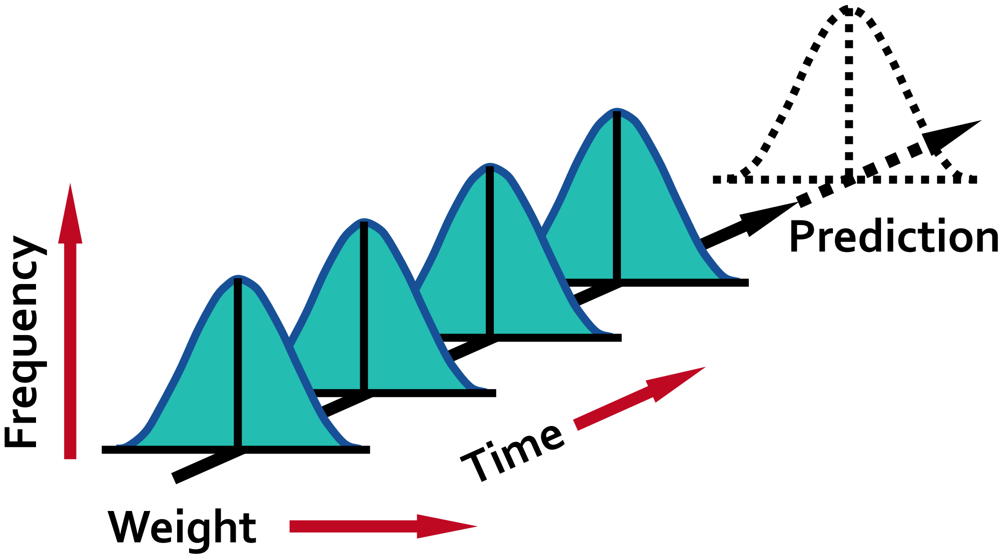
(c) There are many types of distributions, including the normal (bell-shaped) distribution, but distributions do differ in terms of central tendency (mean), standard deviation or variance, and shape



Samples

To measure the process, we take samples and analyze the sample statistics following these steps

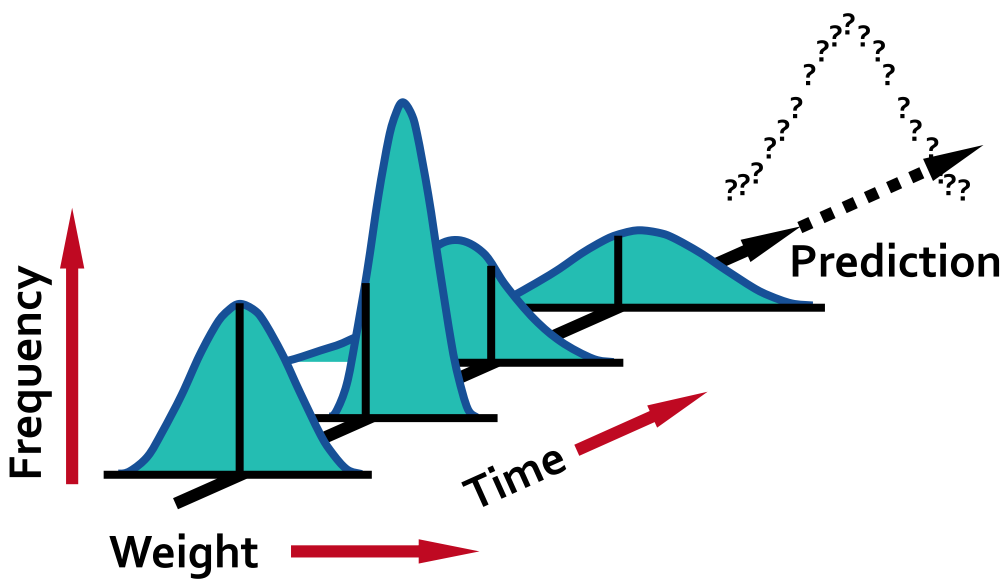
(d) If only natural causes of variation are present, the output of a process forms a distribution that is stable over time and is predictable



Samples

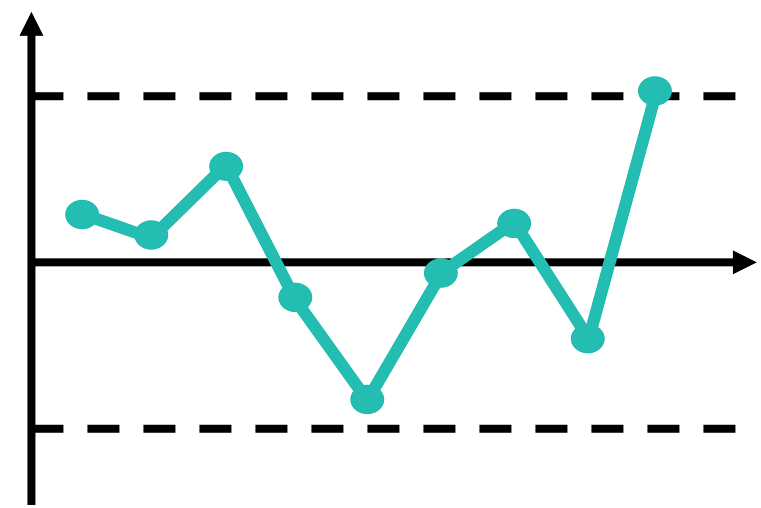
To measure the process, we take samples and analyze the sample statistics following these steps

(e) If assignable causes are present, the process output is not stable over time and is not predicable

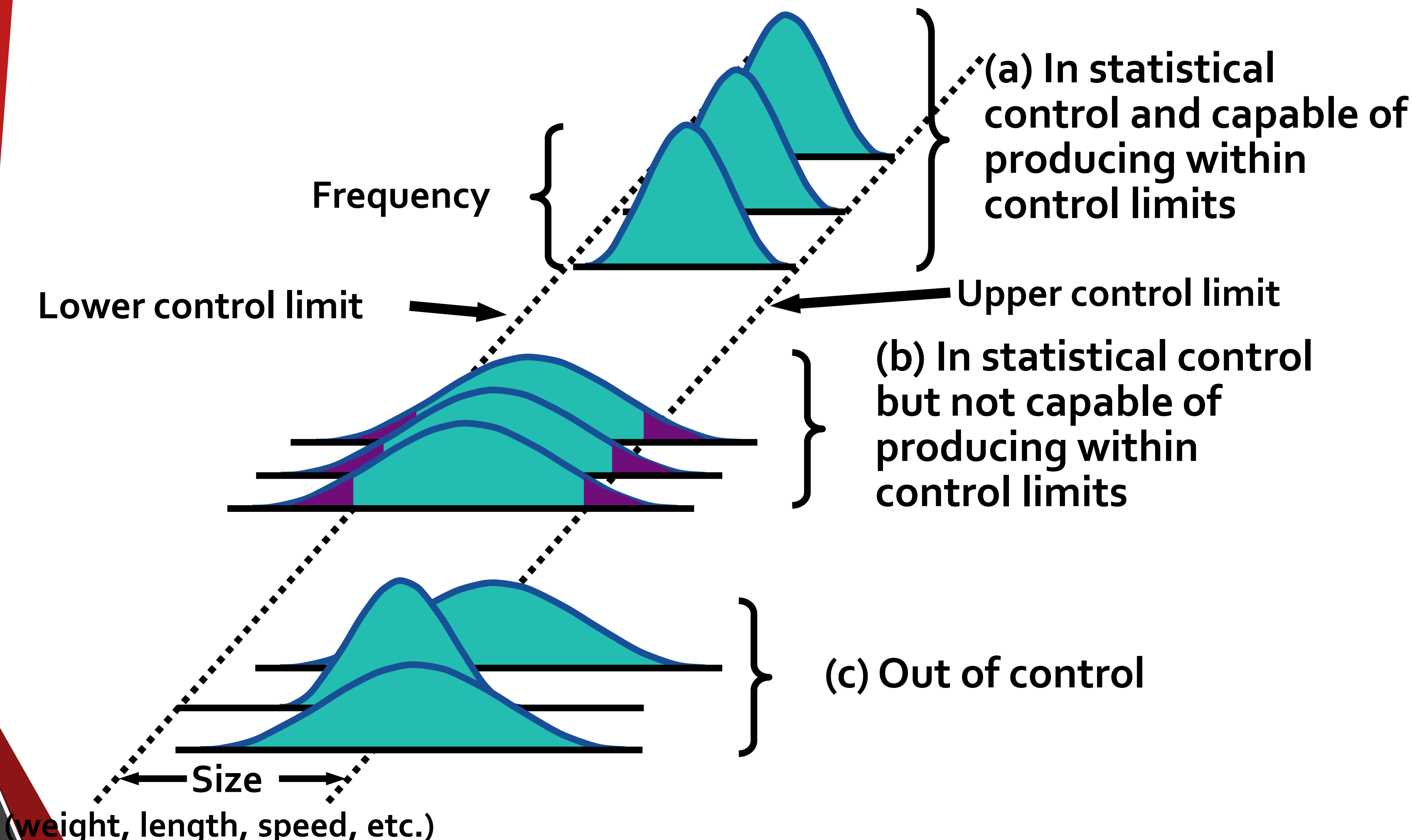


Control Charts

Constructed from historical data, the purpose of control charts is to help distinguish between natural variations and variations due to assignable causes



Process Control



Central Limit Theorem

Regardless of the distribution of the population, the distribution of sample means drawn from the population will tend to follow a normal curve

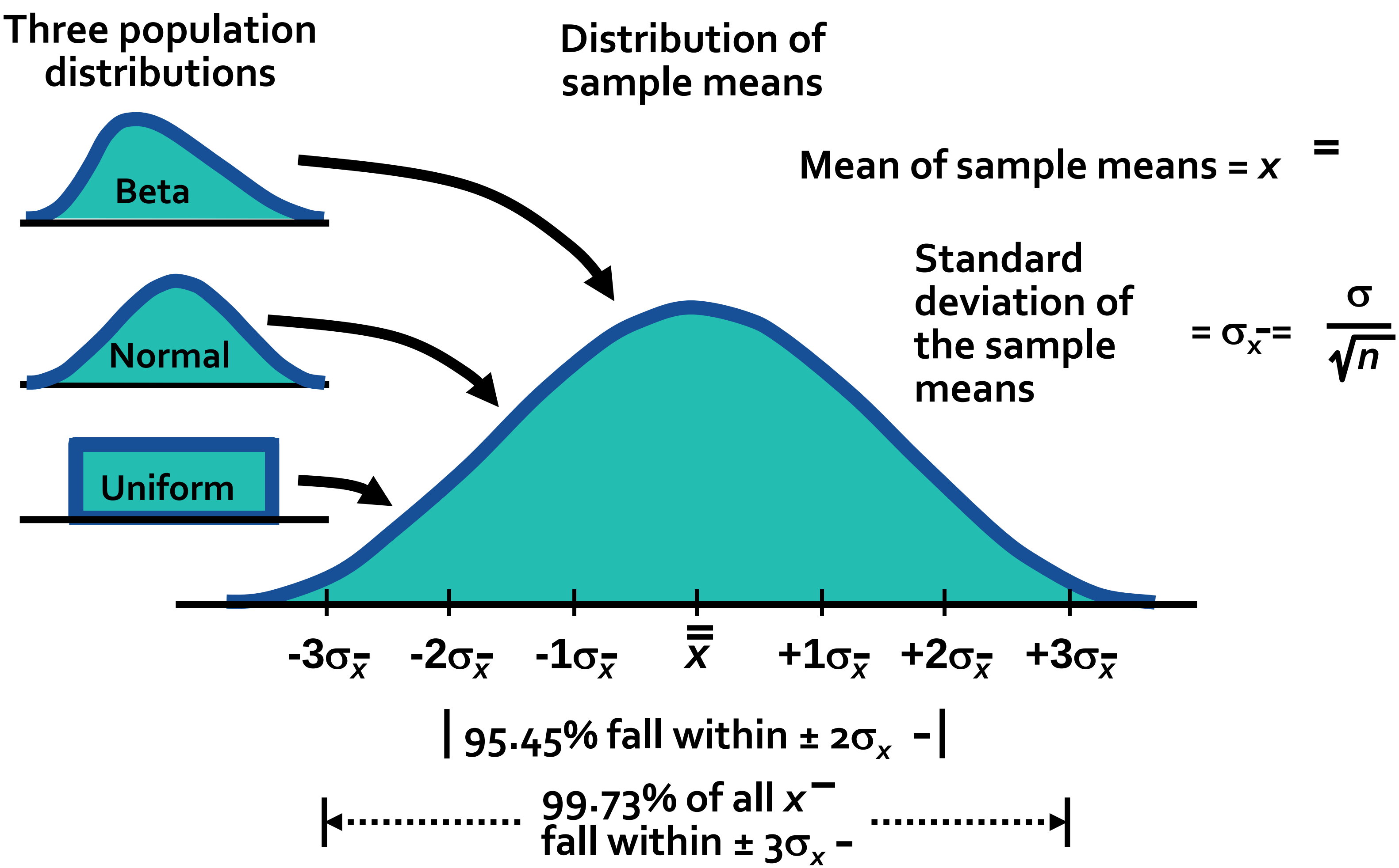
1. **The mean of the sampling distribution ($\bar{\bar{x}}$) will be the same as the population mean μ**

$$\bar{\bar{x}} = \mu$$

2. **The standard deviation of the sampling distribution ($\sigma_{\bar{x}}$) will equal the population standard deviation (σ) divided by the square root of the sample size, *n***

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

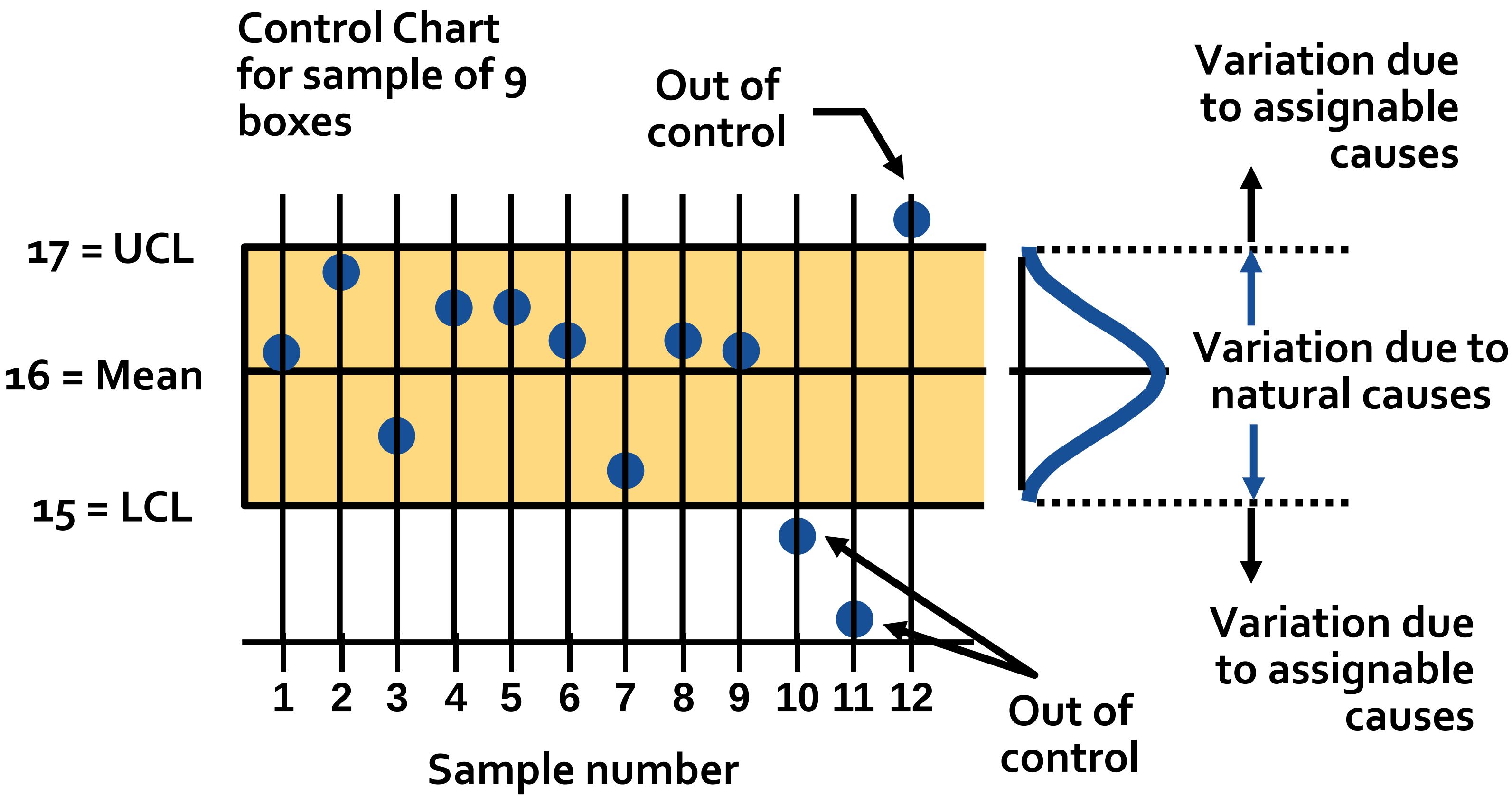
Population and Sampling Distributions



Control Charts for Variables

- **For variables that have continuous dimensions**
  - **Weight, speed, length, strength, etc.**
- **$\bar{x}$-charts are to control the central tendency of the process**
- ***R*-charts are to control the dispersion of the process**
- **These two charts must be used together**

Setting Control Limits



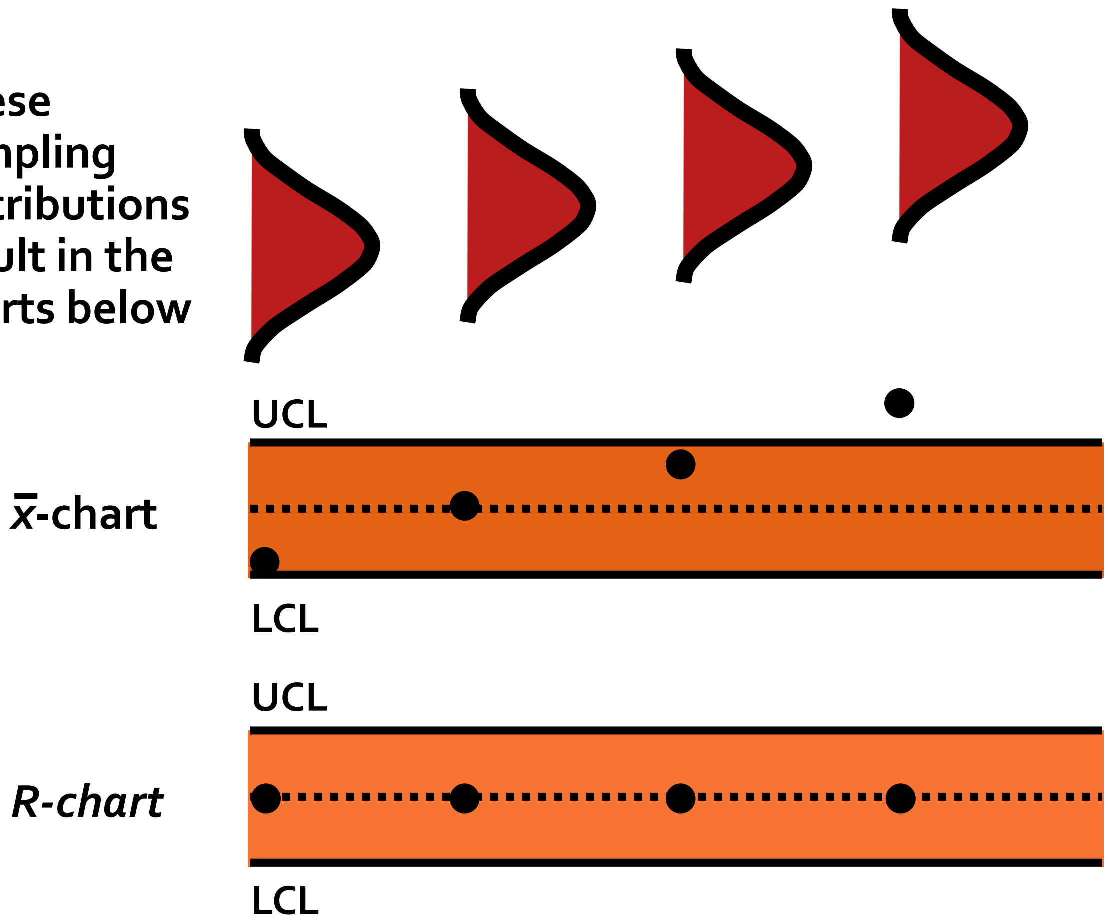
R – Chart

- Type of variables control chart
- Shows sample ranges over time
    - Difference between smallest and largest values in sample
- Monitors process variability
- Independent from process mean

Mean and Range Charts

(a)

These sampling distributions result in the charts below



(Sampling mean is shifting upward but range is consistent)

($\bar{x}$-chart detects shift in central tendency)

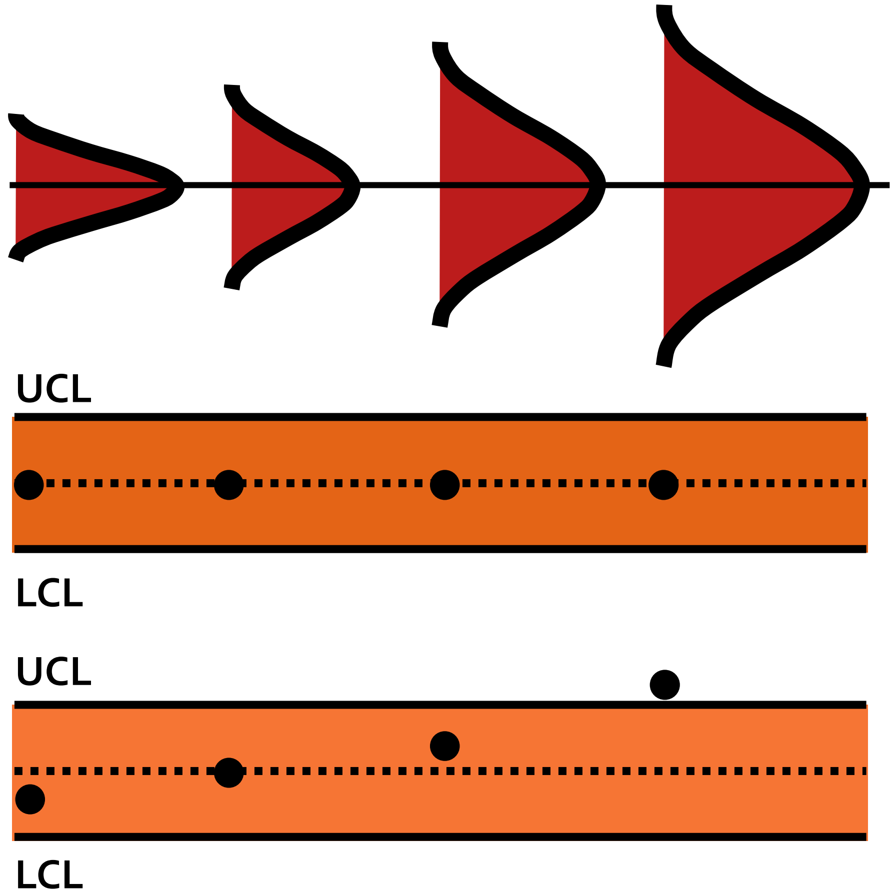
(*R*-chart does not detect change in mean)

Mean and Range Charts

(b)

These sampling distributions result in the charts below

(Sampling mean is constant but dispersion is increasing)



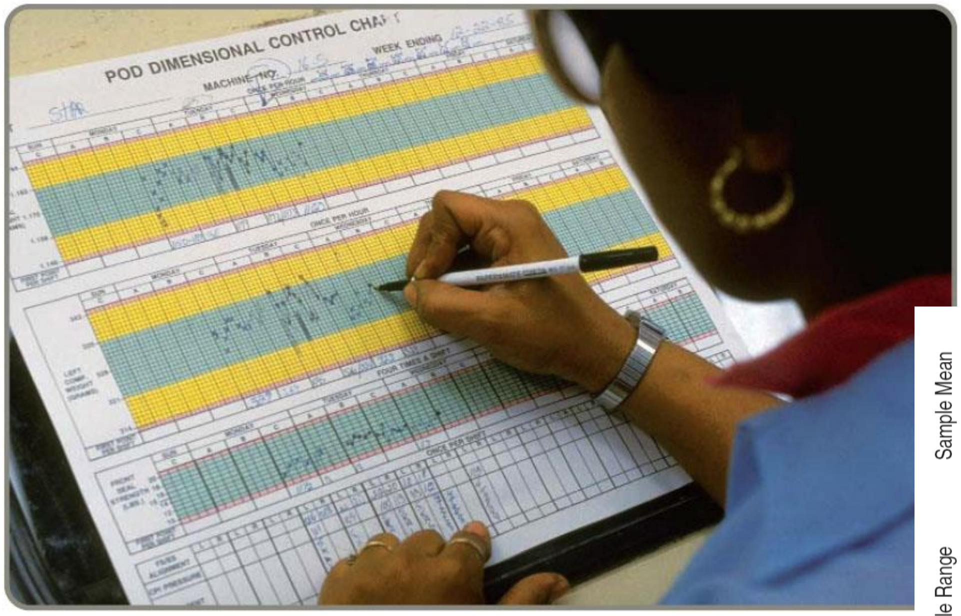
$\bar{x}$-chart

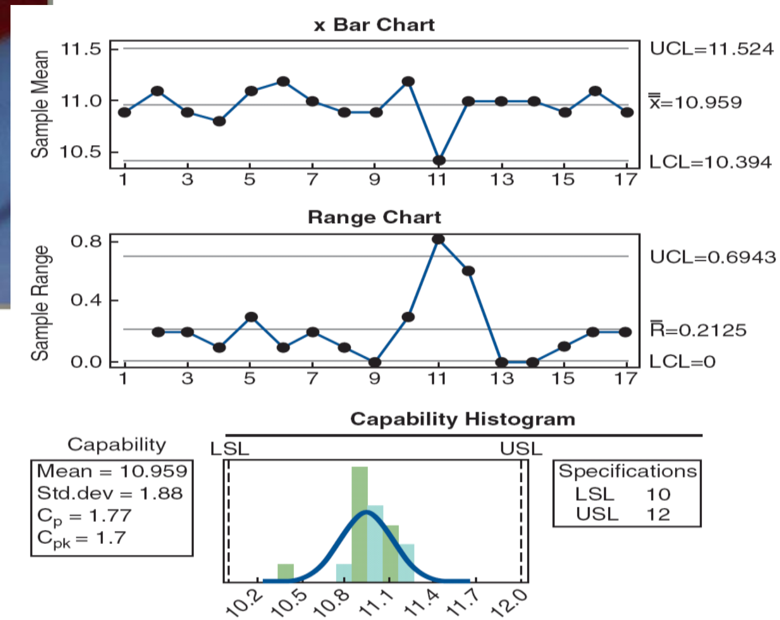
($\bar{x}$-chart does not detect the increase in dispersion)

***R*-chart**

(*R*-chart detects increase in dispersion)

Manual and Automated Control Charts



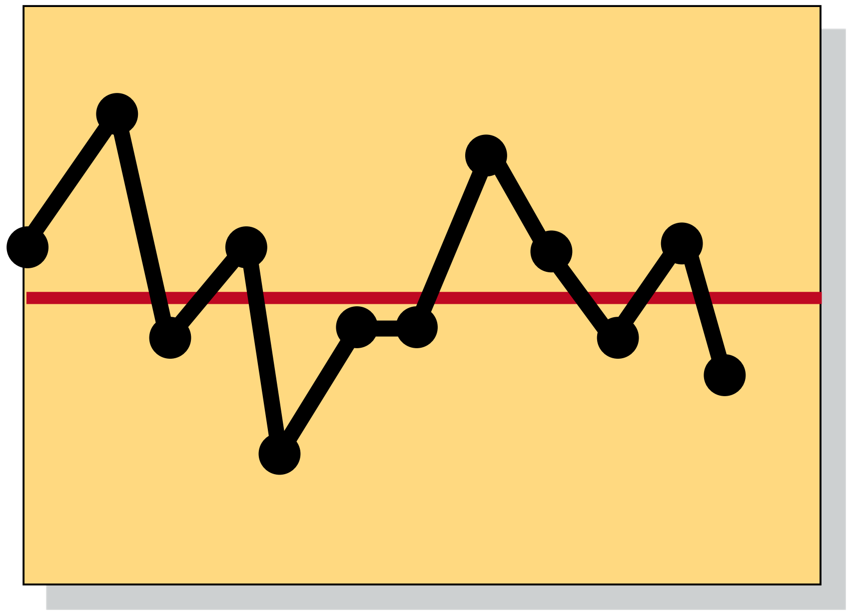


Patterns in Control Charts

Upper control limit

Target

Lower control limit



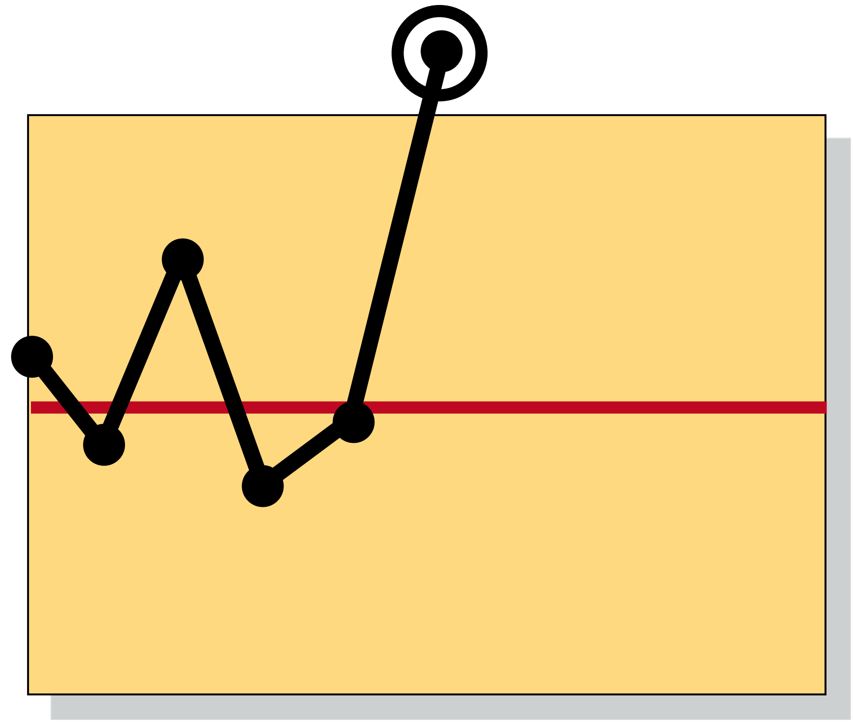
Normal behavior. Process is "in control."

Patterns in Control Charts

Upper control limit

Target

Lower control limit



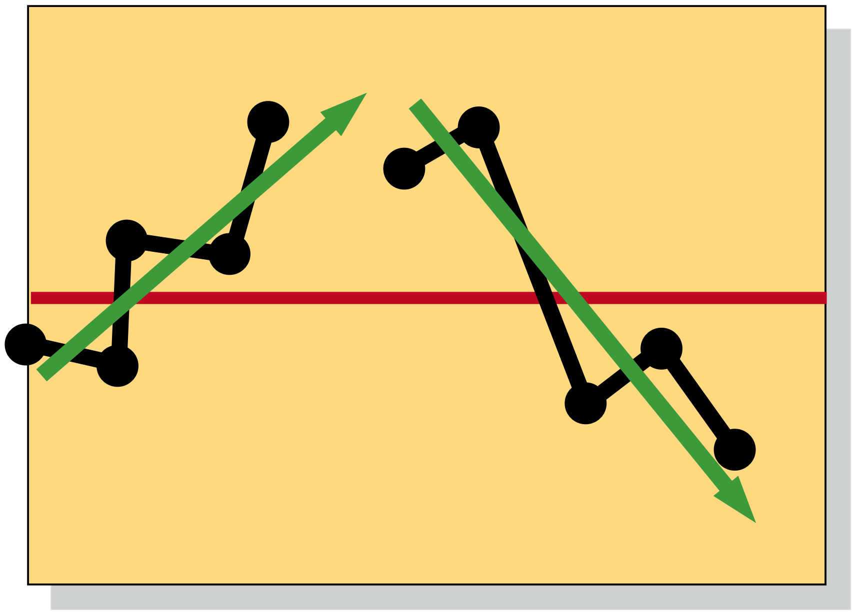
One plot out above (or below). Investigate for cause. Process is “out of control.”

Patterns in Control Charts

Upper control limit

Target

Lower control limit



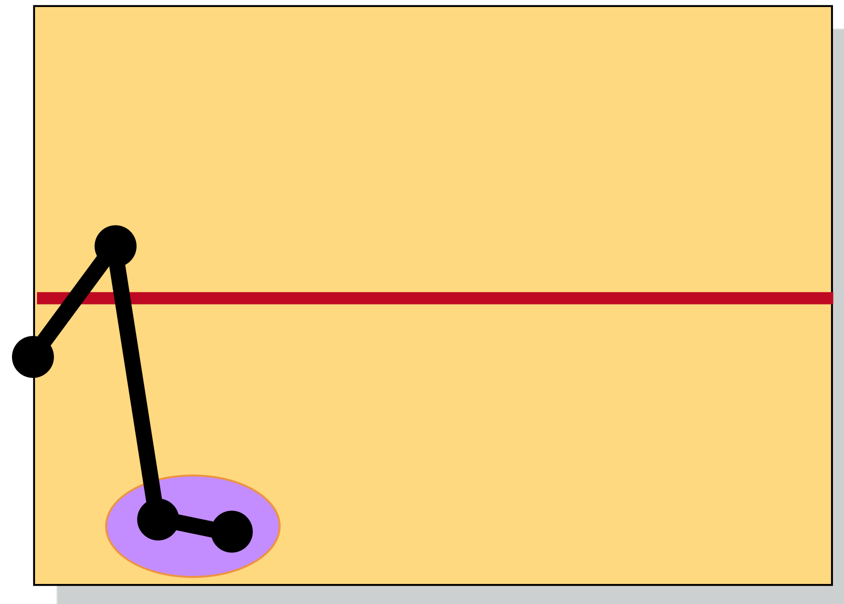
Trends in either direction, 5 plots. Investigate for cause of progressive change.

Patterns in Control Charts

Upper control limit

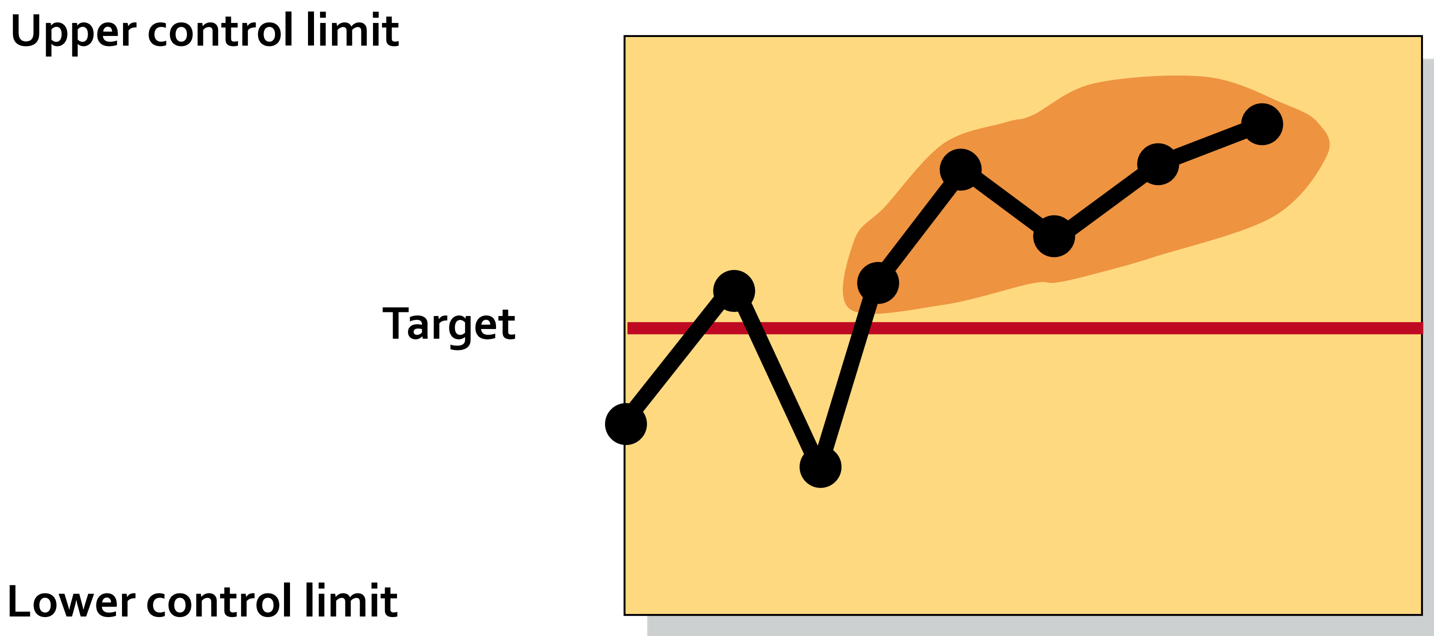
Target

Lower control limit



Two plots very near lower (or upper) control. Investigate for cause.

Patterns in Control Charts



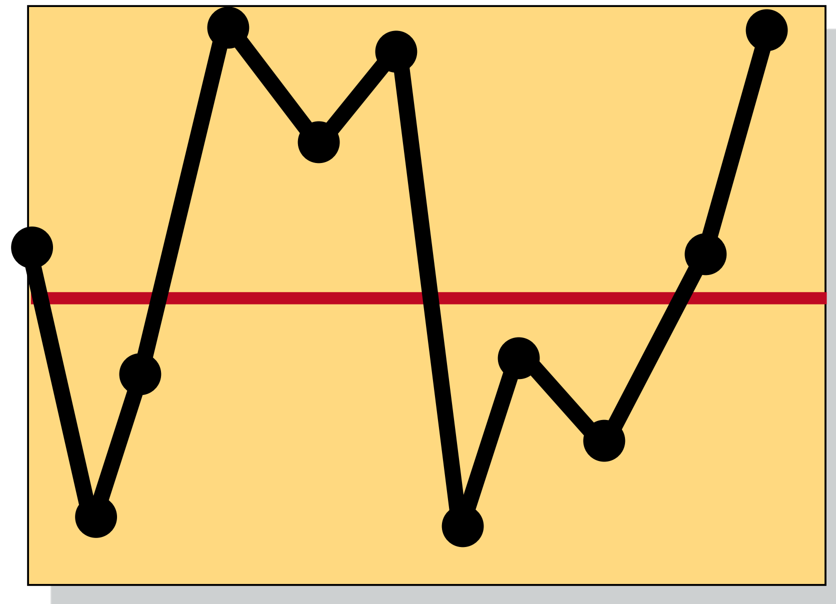
Run of 5 above (or below) central line. Investigate for cause.

Patterns in Control Charts

Upper control limit

Target

Lower control limit



Erratic behavior. Investigate.

Process Capability

- **The natural variation of a process should be small enough to produce products that meet the standards required**
- **A process in statistical control does not necessarily meet the design specifications**
- **Process capability is a measure of the relationship between the natural variation of the process and the design specifications**

Process Capability Ratio

$$C_p = \frac{\text{Upper Specification - Lower Specification}}{6\sigma}$$

- A capable process must have a C_p of at least 1.0
- Does not look at how well the process is centered in the specification range
- Often a target value of $C_p = 1.33$ is used to allow for off-center processes
- Six Sigma quality requires a $C_p = 2.0$

Process Capability **Ratio**

Insurance claims process

Process mean $\bar{x}$ = 210.0 minutes
Process standard deviation σ = .516 minutes
Design specification = 210 ± 3 minutes

$$C_p = \frac{\text{Upper Specification - Lower Specification}}{6\sigma}$$

$$= \frac{213 - 207}{6(.516)} = 1.938$$

Process is capable

Process Capability **Index**

$$C_{pk} = \text{minimum of } \left[\frac{\text{Upper Specification Limit} - \bar{x}}{3\sigma}, \frac{\bar{x} - \text{Lower Specification Limit}}{3\sigma} \right]$$

- **A capable process must have a C_{pk} of at least 1.0**
- **A capable process is not necessarily in the center of the specification, but it falls within the specification limit at both extremes**

Process Capability Index

New Cutting Machine

New process mean $\bar{x}$ = .250 inches
Process standard deviation σ = .0005 inches
Upper Specification Limit = .251 inches
Lower Specification Limit = .249 inches

$$C_{pk} = \text{minimum of} \left[\frac{(.251) - .250}{(3).0005}\right], \left[\frac{.250 - (.249)}{(3).0005}\right]$$

Both calculations result in

$$C_{pk} = \frac{.001}{.0015} = 0.67$$

New machine is NOT capable

Interpreting C_{pk}

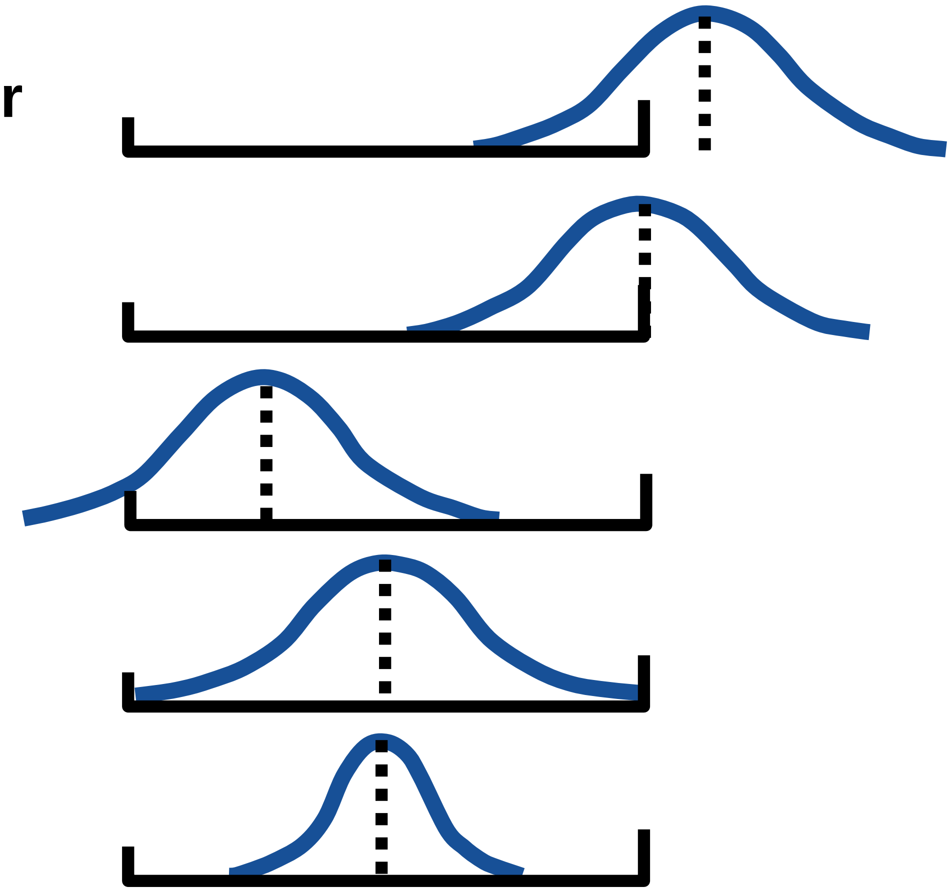
C_{pk} = negative number

C_{pk} = zero

C_{pk} = between 0 and 1

C_{pk} = 1

C_{pk} > 1



Combining two perspectives to find the cause and effects of customer non satisfaction

The Customer Perspective

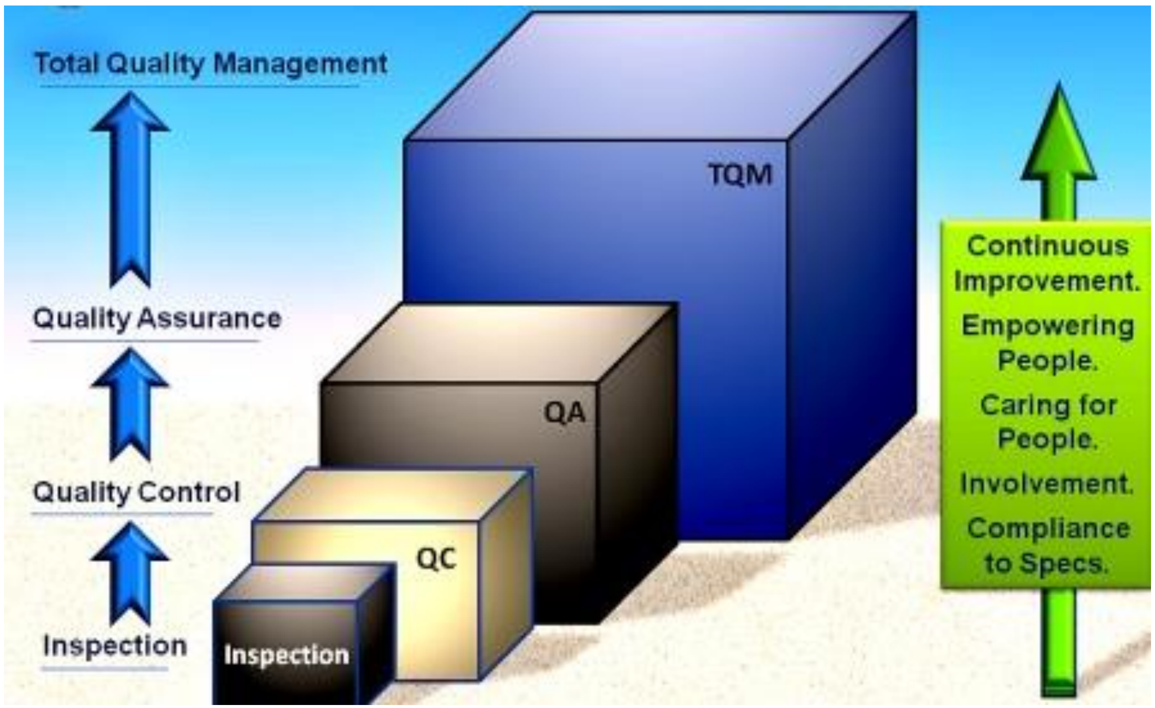
Nonfinancial measures of customer satisfaction include:

- Surveys on satisfaction
- Market share
- Number of defective units shipped to customers
- Number of customer complaints
- Product fail rates
- Delivery delays/On-time deliveries

The Internal Business Process Perspective

- Three techniques for identifying and analyzing quality problems:
  1. Control charts
  2. Pareto diagrams
  3. Cause-and-effect diagrams
- Extending the scope of quality to all departments along the Supply Chain

Total Quality Management moves away from the purely quantiative 6 sigma approach.



Company wide philosophy

Management system

Correction system

Procedure

DMAIC : see scientific article provided

Define

- Review Charter
- Validate Problem statement
- Validate VOC
- Validate $s
- Validate high-level VSM
- Comm Plan
- Select team
- Dev Schedule
- **Complete Define Gate**

Measure

- Dev Ops definitions
- Doc "AS IS" Map – SIPOC
- Dev Data collection plan
- Validate measurement system
- Est. Baseline
- Determine Process Capability
- **Complete Measure Gate**

Analyze

- Determine Critical inputs
- Identify Root Causes (RC)
- Narrow list of RCs
- Determine impact of RCs
- Prioritize RC to be worked
- Analyze "AS IS" for VA vs. NVA
- **Complete Analyze Gate**

Improve

- Dev Potential solutions
- Evaluate, select and optimize best options
- Dev VSM "TO BE" Map
- Pilot
- Confirm attainment of Goals
- Dev Implementation plan
- **Complete Improve Gate**

Control

- Mistake Proof – Poka Yoke
- Dev SOP training plan
- Implement solution
- Est. Process Measurements
- Identify Lessons learned
- **Complete Analyze Gate**
- **Transition to Process Owner**

Kaizen – quick hits

VOC = Voice of the Customer, SIPOC = Supplier Input Process Output Customer, VA/NVA = Value Added, Non Value Added, VSM = Value Stream Mapping, SOP = Standard Operating Procedures